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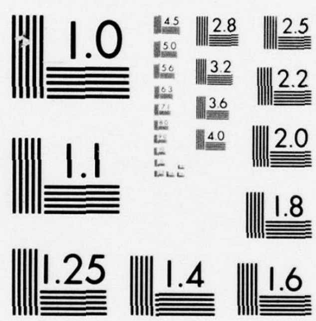

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

6 A LAND TYPE EVALUATION OF THE NAVAJO AND HOPI INDIAN RESERVATIONS USING LANDSAT IMAGES.

9 Master's thesis,

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTERS OF ARTS

12 142 P.

BY

10 JOHNNIE D./SHAW

Norman, Oklahoma

11 1977

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A LAND TYPE EVALUATION OF THE NAVAJO AND HOPI

INDIAN RESERVATIONS USING LANDSAT IMAGES

A THESIS

APPROVED FOR THE DEPARTMENT OF GEOGRAPHY

BY

DEDICATION

In memory of Captain Thomas E. Karstens

A soldier, a gentleman, a friend

ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation and gratitude to a few of the many people who were instrumental in my program here at the University of Oklahoma. To my advisor, Dr. James M. Goodman, goes special thanks for his interest in the Navajo Reservation, both the land and the people, and for his suggestion of the topic for this study. I also want to thank him for his encouragement, willingness to help, and personal interest in my program. Without him this study truly would not have been possible. I thank Dr. Edward J. Malecki for his guidance during the initial portion of my program; for providing motivation and encouragement at times when all seemed for naught; and for his prompt editorial comments and criticisms of this study. I am also grateful to Dr. William C. Johnson for his very detailed critique and his most useful and constructive comments. Mr. T. H. Lee Williams also provided technical insight into the processes and uses of Landsat imagery and provided many useful comments.

Field sampling could not have been accomplished without the hard work of several people. In addition to

Dr. Goodman, Mr. M. Richard Hackett and Ed and Shirley Pugh from the University of Oklahoma and Mr. Bill Gribb from Michigan State University devoted long hours to gathering the field sampling data.

I wish to thank the United States Army for making my studies here at the University of Oklahoma possible. I also express my sincere thanks to my fellow students and members of the faculty in the Geography Department who helped make my stay here a rewarding and memorable experience.

Lastly, I am grateful to my wife, Linda, for her love and continued support throughout my graduate program and for devoting herself unselfishly to our two wonderful children, Chris and Melinda, while I was engaged in the preparation of this study. I also want to thank her for typing and proofreading the final manuscript.

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CHAPTER I

BACKGROUND TO THE STUDY

Introduction

The Navajos are the largest tribe of Indians in the United States living on the largest reservation. Covering an area of more than 24,000 square miles it has been compared in size to the country of Ireland,[1] as containing as much land as New Hampshire, Connecticut, Vermont, and Rhode Island combined and similar in size to West Virginia.[2] The Navajo Reservation also encompasses a smaller reservation which is the home of the Hopi Indians.

Located in the southern portion of the Colorado Plateau, the Reservations extend over an area that varies among sparsely vegetated expanses of desert sand and badlands,

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[1] Wenger J. Hoover, "Navajo Land Problems," <u>Pan American Geologist</u> 65 (May 1936): 248.

[2] Kent Gilbreath, <u>Red Capitalism, An Analysis of the Navajo Economy</u> (Norman: University of Oklahoma Press, 1973), p. 3.

areas of volcanic features, high flat mesas with pinyon and juniper trees, and mountain areas with enormous ponperosa pines and interspersed meadows. It is an area of semi-arid to arid climate with cold winters, hot summers, droughts and blizzards. The land is not hospitable to those who live there and they know that the land does not easily support them.

The Navajo traditional feeling of land abundance and their measure of affluence by the number of sheep and cattle owned, coupled with the poor carrying capacity of this land, led to accelerated soil erosion in the 1930s.[3] Through some rather drastic measures, including forced stock reduction, attempts were made to solve the problem. However, the delicate balance between the people and their land is still a tenuous one. Continuing population increase, coupled with the exploration for and production of energy resources, and planning for vast agricultural projects in an area already lacking in water cause this to be an area still in need of close monitoring in the geographic tradition of man and the land he occupies.

Purpose of the study

The purpose of this study is to delineate, classify and describe a set of land types on the Navajo and Hopi

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[3] Bahe Billy, "Changing The Current Navajo Land Use Patterns and Its Influence On Health," p. 5.

Indian Reservations that might be used as a basis for resource evaluation of the terrain. Land is a composite of many interrelated and integrated parts and exists as a combined entity, not as separate functions of soil, topography, climate or vegetation.[4] The identification of different land types, based on multiple features, has been accomplished in numerous studies using remote sensing techniques. One of the newest tools for making these studies resulted from the launch of ERTS-1 (Earth Resources Technology Satellite) on July 23, 1972.[5] The Landsat image, covering more than 8 million acres, surveys a region through one perspective and the resulting product can provide information on a scale between the highly generalized concept of geographic regions and detailed thematic classes such as soil series or vegetation types. The results should be useful to planners interested in obtaining a general, but complete picture of large areas of land on the Reservations to be utilized for regional planning purposes.[6] Landsat coverage of the Navajo

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[4] D.S. Lacate, "A Review of Land Type Classification and Mapping," Land Economics 37 (August 1961): 271.

[5] This satellite was joined by ERTS-2 on January 22, 1975 and this program has been renamed Landsat, the term which will be used throughout this paper. John B. Rehder, "Landsat Imagery: Pictures of Your Place From Space," The Journal of Geography 75 (September 1976): 354; and National Aeronautics and Space Administration, Landsat (Washington, D.C.: Government Printing Office, 1976), p. 13.

[6] Lacate, p. 272.

and Hopi Indian Reservations provides the input for this study.

Evaluation Procedures

LANDSAT coverage of the Navajo and Hopi Indian Reservations was obtained from 5 overlapping color composite transparencies of the area at a scale of 1:1,000,000. Preliminary visual evaluation of the LANDSAT images was conducted in order to identify visually distinct areas for field sampling. Thirty-six distinct areas were identified for investigation on the Reservations based upon color, tonal and textural variation of the images and commonly recognized physiographic regions of the area. During June, 1976 extensive field work was conducted using these areas. One to five sample sites for each of the 36 areas were designated depending on the complexity and areal extent of the initial areas. Within these 83 sites over 500 detailed samples were taken measuring elevation; slope; types, density and size of vegetation; soil; geology; and landuse.

These sample areas were plotted on USGS topographic sheets at a scale of 1:250,000. An additional 7 color composite images were obtained which had been taken during the same period in which the ground sampling was conducted. Using a standard photographic enlarger, these transparencies were enlarged to the same scale as the USGS map sheets and overlays were constructed to visually delineate land types based on color, tonal and textural similarities on the images. The

resulting land types were compared to the ground sample data to provide ground truth for the maps derived from the LANDSAT images, and to allow determination of those physical variations on the ground which were causing variations on the images.

Quantitative data for the sample areas were then analyzed using correlation and discriminant analysis techniques to determine groupings of land types and any further relationships which might exist between the variables used to measure the sample areas.

The land type classification and resulting maps are the end product of the study and result in a land type classification at a scale of 1:250,000, which should provide a timely base for regional land planning purposes and a framework within which to study more detailed land classifications or thematic aspects of the Navajo and Hopi Indian Reservations.

Theory of Land Type Classification

Although geographers are interested in specific earth phenomena, one of their major concerns is with the total landscape; that is, the relationship among phenomena as they exist on the earth's surface and how these associations vary from place to place.[7] The philosophic basis for the study of landscape can be found as early as 1925 in the writings of Carl Sauer who pointed out that the phenomena which make up

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[7] Nelson R. Nunnally, "Integrated Landscape Analysis with Radar Imagery," Remote Sensing of Environment 1 (1969); 1.

an area are associated with one another and interdependent.[8] He used the term landscape, which he defined as "an area made up of a distinct association of forms."[9] A more recent explanation of this interrelationship of the elements which make up the landscape is found in Kalesnik's law of the wholeness of the landscape envelope. Although each component of the landscape envelope, such as relief, soil, water, and vegetation exists according to its own laws, it also influences each other element of the system. Interaction among the elements creates a unified whole system in which all parts depend on each other and affect each other.[10]

Early work in this area can be found in studies by Ray Bourne with respect to forestry resources. In 1931 Bourne discussed the interaction of the elements within the land system. He stated that the local conditions of an area are influenced by the geographical position, climate, topography, geology, soil, vegetation, animals, and man. These factors determine the environment and were the basis for what he called sites which were areas displaying similar conditions

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[8] John Leighly, ed., Land And Life: A Selection From the Writings of Carl Ortwin Sauer (Berkeley and Los Angeles: University of California Press, 1963), p. 318.

[9] Ibid., p. 321.

[10] S.V. Kalesnik, "General Geographic Regularities Of the Earth," Annals of the Association of American Geographers 54 (March 1964): 160.

of climate, physiography, geology, soil and vegetation. He recognized that the same type of site was evident repeatedly within an area, and he called this association of sites a region. Bourne is regarded as the originator of terrain classification based on recurring land forms and many later researchers have based terrain classifications on concepts which are quite similar to those which he established.[11]

Although the concept of composite units sounds logical, their mapping can be a difficult task. It is not difficult to map one specific thematic topic and by dividing it into either actual or arbitrary classes construct the boundaries between areas. With composite units the problem is that of determining where there is enough change from one or more of the composing conditions to create a new composite unit. Until the advent of aerial photography the mapping of composite land units was almost impossible.[12]

The concept of the land type was developed by J.O. Veatch almost by accident in mapping studies conducted by the Michigan Land Economic Survey in the 1920s. This occurred

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[11] G.A. Stewart, ed., Land Evaluation (Canberra: Macmillan of Australia, 1968), p. 132.

[12] Charles M. Davis, A Study of The Land Type (Ann Arbor: The University of Michigan College of Literature, Science, and The Arts Department of Geography ORA Project 08055, March, 1969), p. 2; and J.S. Rowe, "Why Classify Forest Land?", The Forestry Chronicle 47 (June 1971): 146.

before the advent of aerial photography and was a survey of land use purposes using thematic mapping. There was no intention of mapping composite units, but, when the thematic maps were compared, composite units were observed. These units were considered so obvious in an area of glacial deposition that they were used merely as frameworks within which to arrange more specific data.

Veatch formulated the philosophic basis for the land type approach in several papers in the 1930s. The underlying idea was that land should be classified on a geographic basis by a synthesis of its components such as surface, soil, vegetation and drainage rather than on a single item.[13]

After 1930 the land type concept was used in practical applications by students of Veatch studying in and around Michigan. The idea of the land type in Michigan was discovered rather than designed, and somewhat similar approaches were independently developed elsewhere at the same time. Weeks and his associates used a similar approach in California. The researchers developed a set of land-character types in order to compare the physical characteristics of the land to the land utilization. The land-character types were developed by recording data on climate, soils, topography, natural vegetation and timbersite quality on a series of maps. The maps were then superimposed and the land-character types were de-

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[13] Davis, p. 29.

termined based upon composite classes of vegetation cover, topography, and soils. This procedure was a factorial approach in that each component of the land was classified separately and then combined using a system of overlays to arrive at the final land-character types.[14]

Other examples of the mapping of land types based on landscape characteristics include the Montford Study and the survey of the Tennessee Valley. The Montford Study was another method by which composite units developed somewhat by accident. Vernor C. Finch and his students in southern Wisconsin mapped land conditions in three categories of slope, soil, and drainage. These factors made up the denominator of a fraction with land use in the numerator. A boundary was drawn wherever any of the values changed. Although the maps contained a vast amount of information from which thematic information could be derived, they were based on complete coverage of an area which entailed such extensive field work that Finch questioned the value of the technique.[15] In their 1934 Tennessee Valley Survey G. Donald Hudson and his assistants used airphoto mosaics and developed fractional codes similar to, but much more complex than, those designed by Finch. The basic concepts of the two studies differed in that Finch mapped composite units which were areas within the boundary

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[14] Lacate, p. 273.

[15] Davis, pp. 42-43.

of the most restricted component. This was similar to the work done by Veatch. In the Tennessee Valley study, each unit was differentiated according to some key component on the air photographs, and the characteristics seen in the photographs were assumed to occur throughout the unit.[16] This concept is the basis for the photomorphic approach which will be discussed in a later section.

Marschner, working with the U.S. Department of Agriculture in 1959, is considered to be the pioneer of using aerial photographs to study land practices in the United States. However, his approach was limited to recognizing that various regions had significantly different aerial patterns without applying this in a systematic manner.[17] Two other approaches that were similar to Marschner's were conducted by the Division of Land Research of the Commonwealth Scientific and Research Organization (CSIRO) in Australia and the Military Engineering Experimental Establishment (MEXE) in conjunction with the Soil Science Laboratory of the University of Oxford in Great Britain.

In 1946, CSIRO organized the Northern Australian Regional Survey to "describe, classify and map, and assess

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[16] Davis, p. 44.

[17] Robert G. Reeves, ed.-in-chief, Manual of Remote Sensing, 2 vols. (Falls Church, Virginia: American Society of Photogrammetry, 1975), vol. 2: Interpretation and Applications, by Leonard W. Bowden, ed., p. 1961.

the land use, developmental possibilities, and technical problems"[18] of the area. C.S. Christian and G. Alan Stewart developed both the techniques of the survey and the concept which is called the Land System method. The areas studied were very large and the correlation of aerial photography and ground samples was used extensively. The detailed mapping of individual characteristics was not feasible, therefore complexes of terrain were mapped to form the basis for the land systems. This concept identified environments instead of single features and resulted in the study of the landscape as like or unlike environments.[19] The recognition of aerial photograph patterns and the identification in the field of the terrain factors associated with each pattern was the basis of the method used in this approach.[20]

Although similar to the CSIRO studies in the range of mapping scales (1:250,000 - 1:1M)[21] and the use of composite units, the MEXE - Oxford program was a series of experiments in terrain classification rather than large area mapping.

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[18] Davis, p. 45.

[19] Lacate, p. 274.

[20] Davis, p. 47.

[21] Colin W. Mitchell, Terrain Evaluation (London: Longman Group Limited, 1973), p. 78.

Under the direction of P.H.T. Beckett and R. Webster the objective was to develop a system whereby terrain types could be identified from air photographs and the data stored on cards such that it could be used by others than those who conducted the original analysis. Originally these areas were called recurrent landscape patterns, since then having been replaced by the CSIRO term of land system. It has been shown that these land systems are recurring and can be identified on aerial photographs in conjunction with geologic maps and a small amount of field work. Each land system is homogeneous and different enough from others to be used for predictions within the study area.[22]

Photomorphic Mapping

The photomorphic method is an attempt to look at the total land system and to combine the concepts of two approaches which have been discussed. It incorporates the land systems approach, which is based on basic terrain types, with Marschner's use of patterns on aerial photographs for differentiating types of rural land use. This method was developed by Donald D. MacPhail for use in Chile to study rural landscapes and to cover a large area with limited resources and personnel. The area studied by MacPhail extended over 47,479 square miles.[23] The photomorphic method

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[22] Ibid., pp. 77-78; and Davis, pp. 51-54.

[23] Donald D. MacPhail, "Photomorphic Mapping in Chile," Photogrammetric Engineering 37 (November 1971): 1141.

depicts land types using the patterns produced on aerial photographs by a number of visible characteristics. MacPhail used drainage pattern, drainage density, tone or color range, photographic texture, field size, field pattern, settlement patterns and density of structures in his study.[24] These components appear on the aerial photographs in specific tones, textures and lineaments which produce a composite image representing a specific land type. In other words, definite relationships between components on the ground show up as distinct patterns on the aerial photographs.

The method is advantageous in that patterns, rather than individual components, are differentiated. This compensates for loss of resolution on small scale photos and makes the method ideal for use with satellite imagery. The method is also appropriate for the rapid reconnaissance of large previously unmapped areas, such as the area in Chile mapped by MacPhail. The method has also been utilized for mapping rapidly urbanizing areas within a regional framework as has been done by Janet E. Nichol in her study of Boulder County, Colorado.[25]

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[24] Bowden, p. 1962.

[25] Janet E. Nichol, "Photomorphic Mapping for Land-Use Planning," Photogrammetric Engineering and Remote Sensing 41 (October 1975): 1253. See also Janet E. Nichol, "Land Type Analysis For Regional Land Use Planning From Photomorphic Mapping: An Example For Boulder County, Colorado," Proceedings of the Ninth International Symposium on Remote Sensing of Environment (Ann Arbor: Willow Run Laboratories of Science and Technology, The University of Michigan, 15-19 April 1974, Vol. 1): 589-96.

The method lends itself readily to use with remote sensing techniques in addition to aerial photography. Although he did not refer to it as the photomorphic method, Nunnally used a very similar method in his study of the Asheville Basin in North Carolina. Using radar imagery he outlined variations in the tone, texture pattern and shape which were then correlated with observable variations on the ground. Nunnally used the term integrated landscape to refer to the units which he delimited. He pointed out that although the small scale and limited resolution allow rapid identification of regions, they also restrict the interpretation of detailed variations. He also pointed out that the requirement for ground truth sampling is greatly reduced with this method.[26]

The photomorphic method has been shown to be a reliable means of mapping land types on a regional basis. It is a relatively inexpensive process which is much faster than extensive mapping but is just as accurate when used in conjunction with sufficient sampling to verify the various photomorphic areas.

Role of Landsat Imagery in Land Type Classification

Landsat satellites have been in orbit around the earth since July, 1972, and in that time a wealth of information has been provided concerning the earth's surface. Or-

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[26] Nunnally, p. 1.

biting at an altitude of 910 kilometers (565 miles), Land sat relays complete coverage of the earth, except for the polar regions, once every 18 days. Each frame of imagery covers more than 33,000 square kilometers.[27] Data from Landsat is collected in four different bands of the electromagnetic spectrum. These consist of the green band (band 4) with a wavelength of 0.5-0.8 μm; the red band (band 5) 0.6-0.7 μm; and 2 bands in the near-infrared portion of the spectrum, 0.7-0.8 μm (band 6) and 0.8-1.1 μm (band 7). The two infrared bands measure solar reflectance from the earth's surface outside the range of light sensitive to the human eye. One of the best reflecting materials is chlorophyll, so that, generally speaking, the more dense the vegetation the brighter the reflectance.[28]

False color composites are made by optically combining 3 of the 4 spectral bands to ease the interpretation of the images. Bands 4, 5, and 7 are combined with red being assigned to the near-infrared. Vegetation appears red and the more dense the vegetation, the redder the image. It is sometimes difficult to pick out certain fea-

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[27] Robert G. Reeves, ed.-in-chief, Manual of Remote Sensing, 2 vols. (Falls Church, Virginia: American Society of Photogrammetry, 1975), vol. 1: Theory, Instruments and Techniques, by Frank J. Janza, ed., p. 18.

[28] Charles F. Withington, "ERTS-1 MSS False-Color Composites," in ERTS-1 A New Window On Our Planet, ed. Richard S. Williams Jr. and William D. Carter (Geological Survey Professional Paper 929, Washington, D.C., 1976), p. 3.

tures using only one band or to determine relationships between certain land features and bands, and to facilitate this the false-color composite was developed.[29] Resolution of the images is limited by the smallest element of detection, the pixel, which for currently orbiting satellites is 79 meters square. The limited resolution, coupled with the small scale,[30] allows rapid identification of regions as did radar, but likewise limits the detection of detailed variations.

Landsat imagery readily lends itself to the photomorphic method and the identification of land types. The false color composites improve on a method that had been previously used only with black and white photographs. The distinct color signature of each type of vegetation, crop, water feature, and rock and soil allows greater detail in interpretation.[31] Landsat color composites of the San Joaquin Valley of California have been successfully analyzed using photomorphic pattern identification to differentiate colors, tones and textures on the images of the valley.[32]

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[29] L. Jobin and J. Beaubien, "Capability of ERTS-1 Imagery For Mapping Forest Cover Types of Anticosti Island," The Forestry Chronicle 50 (December 1974): 236.

[30] The scale of an 18.5 x 18.5 cm image, the type used in this study, is 1:1,000,000. Withington, p.3.

[31] Bowden, p. 1971.

[32] Ibid, p. 1966.

Driscoll and his associates utilized Landsat imagery to classify native plant communities in Colorado and successfully interpreted native plant communities at a regional level using visual methods. The investigators state that Landsat imagery allows an "unparallelled opportunity to examine landscape characteristics of large areas."[33] Jobin and Beaubien examined the feasibility of using Landsat imagery to map forest cover types in Canada. These researchers delineated tonal patterns directly from false color transparencies examined on a light table and then transferred them onto a 1:250,000 topographic map sheet. They were able to differentiate fourteen different units on Anticosti Island, which has an area of approximately 8030 square kilometers.[34]

Anderson and others at the U.S. Army Cold Regions Research and Engineering Laboratory used Landsat imagery to study several landscape processes in Alaska. Coastal sedimentation processes were studied in Cook Inlet, and the distribution and environmental interrelationships of permafrost terrain in eight other areas of the state were studied. Using visual interpretation and referring to published maps and other ground truth the researchers were able to identify

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[33] Richard S. Driscoll et al., "ERTS-1 Data For Classifying Native Plant Communities - Central Colorado," Proceedings of the Ninth International Symposium on Remote Sensing of Environment (Ann Arbor: Willow Run Laboratories of Science and Technology, The University of Michigan, 15-19 April 1974, vol. 2): 1195.

[34] Jobin and Beaubien, pp. 235-236.

and delineate seven surficial geology, eight vegetative cover and four permafrost terrain units. These researchers felt that Landsat imagery exceeded their expectations in its use for land type classification and that the detail available from the 1:1,000,000 scale Landsat imagery compared favorably to the detail available on U.S. Geological Survey maps at a scale of 1:250,000.[35] In their land evaluation study of Pennington County, South Dakota, Frazer and others used color composite transparencies, single band transparencies and enlargement prints to produce a soilscape map for the area. They determined that the color composite transparencies were the most useful in determining boundaries between soilscape areas, and that the interaction between the individual bands aided in the interpretation. Frazer and his associates felt that the advantages gained by using Landsat imagery included the synoptic view which allowed large areas to be studied from the same perspective and the multispectral capability which improved the ability of the researchers to distinguish soil differences. They also determined that the imagery can be enlarged to 1:250,000 without

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[35] D.M. Anderson et al., "The Use of ERTS-1 Imagery In the Regional Interpretation of Geology, Vegetation, Permafrost Distribution and Estuarine Processes In Alaska," in Remote Sensing of Earth Resources, ed. F. Shahrokhi (The University of Tennessee: Tullahoma Tennessee Space Institute, 1972), pp. 1049, 1052, 1053, 1070.

the loss of detail.[36]

These studies point out that the photomorphic method of identifying land types by using tones and textures can be extended to use with Landsat false color composites, thereby incorporating the additional advantage of color differentiation. The land types identified on images can be verified by a much smaller amount of ground sampling, which both speeds the process of identification and greatly reduces the expense involved. Finally, the 1:1,000,000 color transparencies can be enlarged to 1:250,000 to make them compatable with the U.S. Geological Survey topographic map coverage of the United States. All of these advantages made Landsat imagery the best system to use in this study.

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[36] C.J. Frazer et al., "Use of ERTS-1 Imagery For Land Evaluation In Pennington County, South Dakota," Proceedings of the Ninth International Symposium on Remote Sensing of Environment (Ann Arbor: Willow Run Laboratories of Science and Technology, The University of Michigan, 15-19 April 1974, vol. 1): 549, 551, 552.

CHAPTER II

THE STUDY AREA

Delimiting the Study Area

The Navajo and Hopi Indian Reservations are located in portions of Apache, Navajo and Coconino Counties in northeastern Arizona; San Juan and McKinley Counties in northwestern New Mexico and San Juan County in southeastern Utah.[1] The Hopi Reservation lies in the central portion of the Navajo Reservation in the Arizona counties of Coconino and Navajo and is surrounded by a much disputed Joint Use Area which has been the subject of litigation between the two tribes.[2] To the east of the Navajo Reservation proper is the Eastern Agency which is also called the checkerboard area because it is made up of alternating sections of Indian land

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[1] M.E. Cooley et al., Regional Hydrology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico and Utah (Geological Survey Professional Paper 521-A, Washington, DC., 1969), p. A2.

[2] See James M. Goodman and Gary L. Thompson, "The Hopi - Navaho Land Dispute," American Indian Law Review 3 (December, 1975).

interspersed with sections (one square mile areas) which are part of the public domain or privately owned. There are also three Navajo bands who occupy reservations not coterminous with the main Reservation: Ramah, Alamo and Canoncito Reservations.

For the purpose of this study only the area of the Navajo and Hopi Reservations proper is being studied (Figure 1). The checkerboard area and the three noncontiguous areas are not included. The boundary between the Hopi and Navajo Reservations is one of administrative rather than natural significance and other than being initially pointed out will not enter into the study.[3] The study area lies between 35° and 37°30' north latitude and 108°15' and 112° west longitude. The Puerco, Little Colorado, Colorado, and San Juan Rivers border or approximately define the Reservation on three sides and form somewhat of a natural boundary that has long been recognized by the tribes in the area.[4] The eastern boundary is roughly the Continental Divide.

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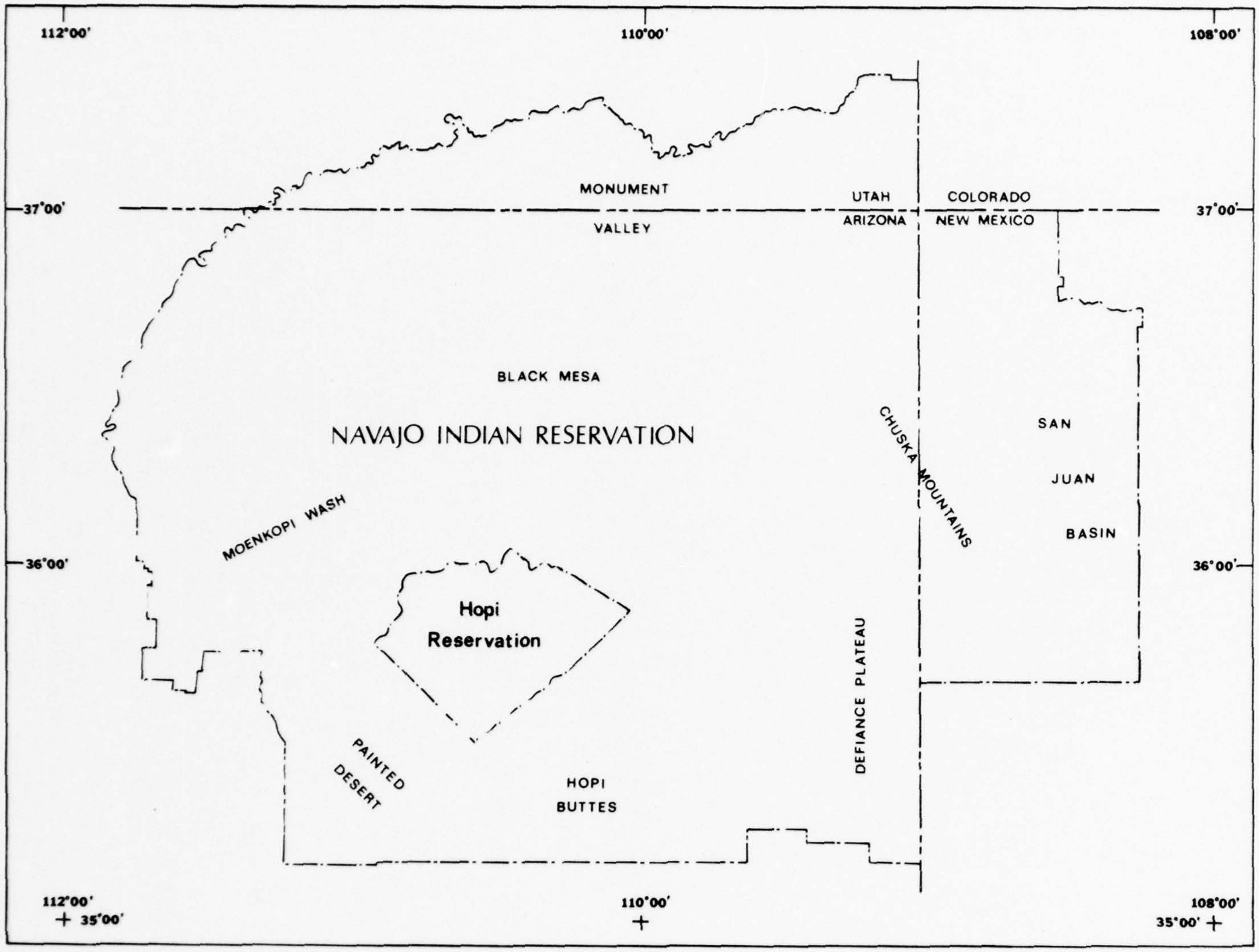
[3] This is evidenced by a 1974 Act of Congress which requires an adjustment of the boundary between the two reservations to eliminate the Joint Use Area. However, since the matter has only been recently resolved (February, 1977) the traditional boundary of the Hopi Reservation is reflected in this study.

[4] Herbert E. Gregory, Geology of the Navajo Country (Geological Survey Professional Paper 93, Washington, D.C., 1917), p. 11.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MONUMENT
VALLEY
UTAH
ARIZONA
COLORADO
NEW MEXICO
BLACK MESA
NAVAJO INDIAN RESERVATION
CHUSKA MOUNTAINS
SAN
JUAN
BASIN
MOENKOPI WASH
Hopi
Reservation
DEFIANCE PLATEAU
PAINTED
DESERT
HOPI
BUTTES

Figure 1

Physiography

The Navajo and Hopi Reservations lie within the Colorado Plateau Province. The Colorado Plateau is recognized by most authors as being divided into six sections; one of these is the Navajo Section which encompasses all of the study area[5] (Figure 2). The Navajo Section is recognized as a somewhat poorly defined area bordered by the rivers previously mentioned and rather arbitrarily defined along its other borders. Fenneman derived his boundary for the southern and southwestern section from Gregory's definition of the Navajo Country.[6] However, Gregory arbitrarily drew the eastern boundary along the 108th meridian and constructed the southern boundary along the Santa Fe Railroad.[7] This boundary has no physiographic significance and has been pointed out by Hoover as an example of cultural or geographic factors outweighing physiographic considerations in determining the boundary for a physiographic region.[8] The terrain of this area has been variously described by many authors, and

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[5] William D. Thornbury, Regional Geomorphology of the United States (New York: John Wiley and Sons, Inc., 1965), pp. 416-417; and Nevin M. Fenneman, Physiography of Western United States (New York: McGraw-Hill, 1931), p. 278.

[6] Gregory, p. 11.

[7] Ibid.

[8] J. Wenger Hoover, "Physiographic Provinces of Arizona," Pan-American Geologist 65 (June 1936): 328.

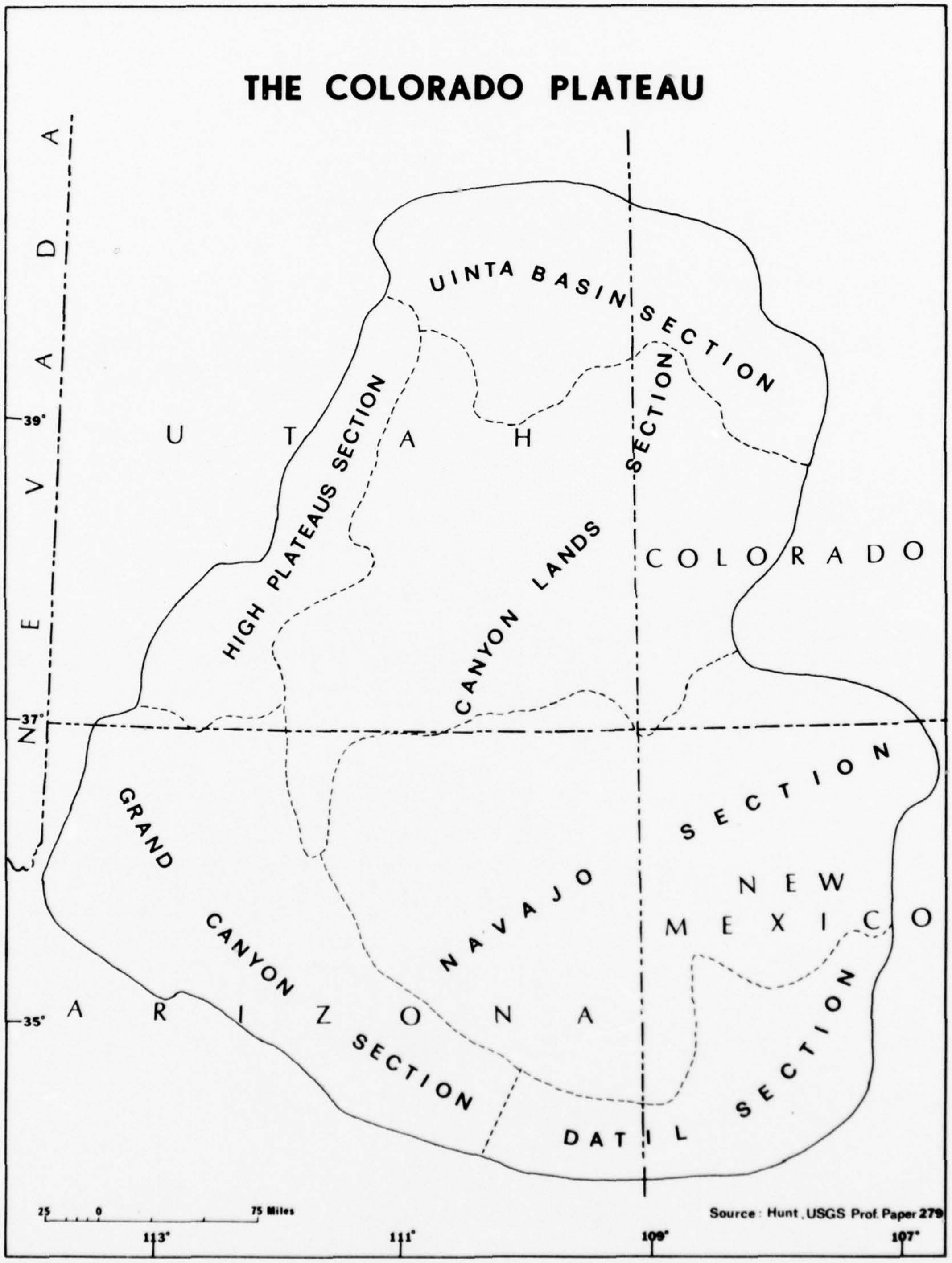
THE COLORADO PLATEAU
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
UINTA BASIN SECTION
HIGH PLATEAUS SECTION
CANYON LANDS SECTION
GRAND CANYON SECTION
NAVAJO SECTION
DATIL SECTION
39°
37°
35°
113°
111°
109°
107°
25 0 75 Miles
Source: Hunt, USGS Prof. Paper 279

Figure 2

although some degree of agreement exists differences in generalizations abound. Kluckhohn and Leighton described the area thusly:

> Set a stretch of sagebrush interspersed with groves of small evergreens (pinyons and juniper trees) against a background of highly colored mesas, canyons, buttes, volcanic necks, and igneous mountain masses clothed in deep pine green, roofed with a brilliant blue sky, and you will have a generalized picture of the Navajo landscape.[9]

On the other hand, Cooley and his associates managed to identify eleven distinct hydrogeologic subdivisions.[10] Further, Gregory divided the area into twenty physiographic subdivisions.[11]

The landforms in this area are composed primarily of sandstones and shales. The area is similar in elevation to the Canyon Lands section of the Colorado Plateau but is much less dissected, primarily because the Navajo Section is not traversed by large active streams. It is an area of broad, open valleys and mesas. In this arid to semi-arid climate, land forms such as mesas, cuestas, rock terraces, retreating escarpments, canyons, and dry washes are

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[9] Clyde Kluckhohn and Dorothea Leighton, The Navaho (Harvard University Press, 1946; The Natural History Library Anchor Books, 1962), p. 45.

[10] Cooley, p. A22.

[11] Fenneman, p. 313.

common.[12] Alternating layers of weak and resistant rock stata affect slope configurations of this region; ledges, cliffs and mesas are formed by the resistant rock while the weaker shale formations are responsible for the slopes, valley floors and badlands.[13]

The regional landforms reflect the broad structural patterns of the region. Altitudes range between 5000 and 10000 feet. A lack of deep canyons in this area is not due to a lack of elevation above base level but because of the lack of permanent streams. The San Juan River is the only permanent stream and it receives runoff from the higher San Juan Mountains northeast of the Navajo Section. Overall precipitation averages only 8 to 12 inches annually with greater amounts in the higher elevations. However, in the western sections less than 3 inches of rainfall annually is sometimes the case.[14]

The major structures consist of two large basins, the San Juan on the east and the Black Mesa on the west which are separated by the north-south trending Defiance Plateau (an asymmetrical anticlinal structure) (Figure 1). The Black Mesa basin, consisting of Permian to Tertiary age strata, is

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[12] Fenneman, p. 312; and Charles B. Hunt, Cenozoic Geology of the Colorado Plateau (Geological Survey Professional Paper 279, Washington, D.C., 1956), pp. 2 and 6.

[13] Cooley, p. A21.

[14] Cooley, p. A27; and Thornbury, pp. 432-433.

the smaller of the two, being about 90 miles in diameter. The central area of this basin is a topographic high (Black Mesa) capped by sandstone with eroded escarpments on all sides which are much higher and pronounced on the north and east. The deeper San Juan basin is in the eastern portion of the Navajo Reservation. It is a structural and topographic basin some 5000 feet deep comprised of Tertiary aged fill over rocks of late Cretaceous age. Both of these basins contain coal-bearing formations, a feature whose impacts will be discussed in more detail later in this chapter.

The Defiance uplift, which separates the two basins, is a north-trending asymmetrical fold 100 miles long and 30 miles wide. Along the east side of the uplift is the east-dipping Defiance monocline near the Arizona-New Mexico border. Along this monocline lie the Chuska Mountains, a narrow strip of Tertiary sandstone. These mountains have many areas above 8000 feet with crests above 9000 feet. The tops of these mountains are relatively flat areas containing hundreds of rather enigmatic depressions and lakes which Wright has argued are caused by collapse due to piping and roofing of subsurface water flow in the region.[15]

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[15] H.E. Wright Jr., "Origin of the Lakes in the Chuska Mountains, Northwestern New Mexico," Geological Society of America Bulletin 75 (July 1964): 594. These depression areas are being pointed out because in the present study they appear very prominently on Landsat images of the area. They result in one of the land type classifications which has been named Chuska Summit because of its distinctive pattern and color.

South of the Black Mesa basin is an area known as the Painted Desert which is distinguished by magnificently colored badlands. In the center of this area is a clustering of volcanic buttes, necks, lava flows and diatremes which are known as the Hopi Buttes.[16] This area is not the only portion of the Reservation which displays volcanic features. Shoemaker identified nearly 250 necks and diatremes on the Reservations with about 200 of these in the Hopi Buttes area, 20 in the north central portion of the Reservation in Monument Valley and 36 in the Chuska Mountains.[17]

Vegetation and Land Resource Regions

Vegetation on the Navajo and Hopi Reservations can be divided into three broad categories based on elevation. The grass-shrub zone is below 5500 feet and includes badlands and areas of extensive arid deflation and dunes. The climate at these lower elevations results in the sparse vegetation cover with precipitation generally less than 8 inches annually and maximum daily summer temperatures in excess of 100°F. Vegetation in this zone consists mainly of isolated clumps of grass with sparse shrub growth consisting of

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[16] Cooley, p. A23.

[17] Thornbury, p. 413.

greasewood and sagebrush.[18] Widely scattered stands of juniper or pinyon also occur in this zone. Denser areas of vegetation can be found near water sources such as springs, seeps, and ephemeral streams. The principal trees near water sources are the cottonwood, willow and salt cedar (tamarisk). The latter is an alkali-tolerant shrub which was not native to this area, but is believed to have been introduced to the region by the Spanish and has rapidly spread along the stream valleys in this region during the past 40 years.[19]

The pinyon-juniper zone extends from 5500 to 7500 feet and is, as the name explains, dominated by pinyon and juniper trees. Land in this zone includes a variety of landscapes: gently rolling areas, steep hillsides and ridges, and deep canyons. Grass is interspersed with the pinyon, juniper, and sagebrush; is much larger and denser than in the lower elevations; and occurs on mesa tops and on other flat-lying surfaces. Shrubs such as mountain mahogany, bearberry

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[18] Throughout this study only the common names of the species will be used. A very good source for the scientific names of the species on the Reservations is contained in the Appendix to <u>Guide to Improvement Of Arizona Rangeland</u>, Bulletin A-58, The University of Arizona Cooperative Extensive Service and Agricultural Experiment Station.

[19] David R. Harris, "Recent Plant Invasions In the Arid and Semi-arid Southwest of the United States," in <u>Man's Impact on Environment</u>, ed. Thomas R. Detwyler (New York: McGraw-Hill, 1971), pp. 468-471.

and cliffrose are found along the hillsides and ridges. The success of grass in this zone depends on the underlying material and tends to be good in areas underlain by sandstone, moderate in limestone areas and poor in areas underlain by mudstone and siltstone.[20]

The highest elevational zone on the Reservation is the pine-forest zone which is dominated by ponderosa pine forests and extends above 7500 feet where precipitation of more than 15 inches occurs annually. This zone includes areas on the Defiance Plateau, the Chuska Mountains and Navajo Mountain and small areas on Black Mesa. In addition to ponderosa pine this zone includes Douglas fir, aspen, and oak. Well-watered meadows of grass can be found in many of the higher elevations of the Chuska Mountains. There is little effect on soil formation in the pine forests by the underlying rock, and therefore little association between the rock outcrops and the vegetation types in this zone. For the most part, the type and amount of vegetation is controlled by the precipitation, slope, exposure and availability of soil moisture.[21]

The U.S. Department of Agriculture has classified land in the United States into 20 land resource regions for the purposes of "farming, ranching, forestry, engineering,

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[20] Cooley, p. A32.

[21] Ibid.

Jobin and Beaubien, pp. 235-236.

recreation, and other uses."[22] These resource regions are further divided into 156 major land resource areas. The Navajo and Hopi Reservations lie in the Western Range and Irrigation Region (Land Resource Region D), which covers 545,200 square miles across Texas, New Mexico, Arizona, Utah, Nevada, California, Idaho and Oregon. Portions of four of the major land resource areas are contained within the Reservations (Figure 3). The San Juan Basin area is located within Area 37 (San Juan River Valley Mesas and Plateaus) which is defined as an area of 5000 to 6000 feet in elevation with gently sloping broad valleys and plains bordered by deeply dissected bands of steep slopes. The vegetation is desert shrubs and short grasses with pinyon-juniper woodlands at the higher elevations. The Chuska Mountains comprise the part of Area 39 (Arizona and New Mexico Mountains) located on the Reservations. At the lower elevations this area is in mixed grasses and pinyon-juniper woodlands whereas the upper mountain slopes and crests are in ponderosa pine. The elevation ranges from 4500 to nearly 10,000 feet and consists primarily of steep mountains and foothills. A small area of the Defiance uplift is contained in Area 36 (New Mexico and Arizona Plateaus and Mesas) which is described as gently rolling plains between 6000 and 6500 feet vegetated

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[22] U.S. Department of Agriculture, Soil Conservation Service, Land Resource Regions and Major Land Resource Areas of the United States by Morris E. Austin, Agricultural Handbook 296 (Washington, D.C.: Government Printing Office, 1965), p. 1.

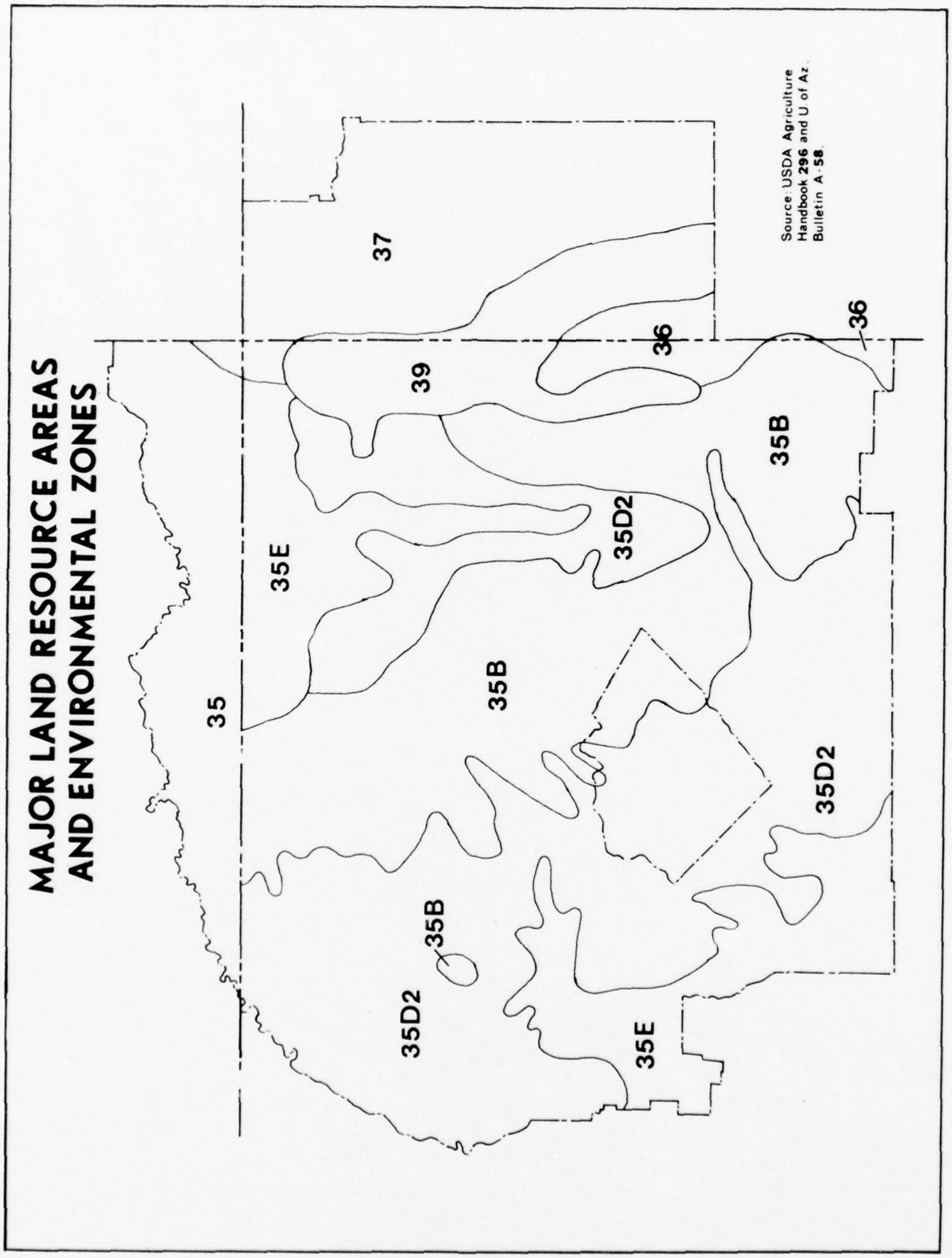
MAJOR LAND RESOURCE AREAS
AND ENVIRONMENTAL ZONES
35
35E
35B
35D2
39
36
37
35B
35D2
35B
35D2
35E
Source: USDA Agriculture
Handbook 296 and U of Az.
Bulletin A-58.

Figure 3

by pinyon and juniper, rabbitbrush, and sagebrush. The remainder of the Reservations is in Area 35 (Colorado and Green River Plateaus), identified by open grass-shrub areas with pinyon-juniper woodlands on the higher plateaus and mesas located from 5000 to 7000 feet. The University of Arizona Cooperative Extension Service has divided this area into four Environmental Zones (Figure 3). These are the Colorado Plateau Salt-Desert Shrub zone (Environmental Zone 35E) with elevations from 4500 to 5000 feet and groundcover of saltbush and greasewood; the Colorado Plateau Shortgrass zone (Environmental Zone 35D2) extending between 5000 and 6000 feet characterized by some grass and sagebrush; the Colorado Plateau Woodland-Sagebrush (Environmental Zone 35B) occurring between 5000 and 7000 feet and characterized by large sagebrush, pinyon and juniper and the Springerville Shortgrass Plains (Environmental Zone 35D1) between 6000 and 7500 feet elevation with gramagrass and wheatgrass as the major vegetation cover.[23] Even at the state level these land resource units are very broad descriptions when applied to the Reservations. It is hoped that the land types identified in this study will provide the more detailed breakdown of land types which will be useful in regional planning on the Reservations.

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[23] Land Resource Regions and Major Land Resource Areas of the United States, pp. 15-17 and map (in pocket); and Guide to Improvement of Arizona Rangeland, pp. 20-21.

Future Impacts In This Area

In addition to providing a land type evaluation of the Navajo and Hopi Reservations study in this area has importance due to three other factors. These factors are population increase, energy resources, and economic development. The annual population growth on the Navajo Reservation is 3.89 per cent which is far in excess of the average growth rate for the remainder of the United States. Today there are 5.4 persons per square mile on the Navajo Reservation which is more than twice that of nearby rural areas populated by non-Indians. Coupled with the relatively unproductive nature of the land, this area is overcrowded considering the population it can viably support. In an area estimated to support only 35,000 people through agriculture live a population in excess of 140,000 people.[24]

Oil, coal and uranium, all important in the production of energy, have been found in various quantities on the Reservations and are in varying stages of exploration and production. Energy production from coal fired electric generating plants is already occurring on the Navajo Reservation and several more projects are planned. Two of these, the San Juan and the Four Corners power plants, are located approximately 20 miles west of Farmington, New Mexico. The

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[24] Johnnie D. Shaw, "Population on the Navajo Reservation - Past, Present and Future Trends," Indian Lands and Resources Seminar, Norman, Oklahoma, 14 December 1976.

Four Corners Powerplant is located on the Reservation and is currently in operation. The San Juan Powerplant is located 8 miles north of the Four Corners plant and off the Reservation. This plant is in operation with continued expansion planned into the 1980s.[25] Two coal gasification projects are proposed for this area. One project, by Western Gasification Company (WESCO), will operate four plants on the Reservation 27 miles southwest of Farmington. These plants, if construction was started immediately, would not be operational until 1985. Another proposed gasification project on the Reservation, by El Paso Natural Gas Company, will be 15 miles southeast of the WESCO plants and will consist of two plants. Additional projects in this eastern area of the Reservation include the Navajo-Exxon Uranium Project and the Navajo Indian Irrigation Project. The Exxon project consists of exploration, mining and milling of uranium in the western third of San Juan County. The Navajo Indian Irrigation Project consists of the irrigation and farming of 110,630 acres, including the associated agribusinesses.[26]

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[25] U.S. Department of the Interior, Bureau of Reclamation, Western Gasification Company (WESCO) Coal Gasification Project and Expansion of Navajo Mine By Utah International Inc. Final Environmental Statement, 14 January 1976, pp. 1-17, 1-18.

[26] Shaw, pp. 16-17. See also U.S. Department of the Interior, Bureau of Indian Affairs, Planning Support Group, Uranium Exploration, Mining and Milling Proposal Navajo Indian Reservation, New Mexico Draft Environmental Impact Statement; and U.S. Department of the Interior, Bureau of Indian Affairs, Navajo Indian Irrigation Project Draft Environmental Statement, (DES 76-20).

Although not directly related to this study, these projects and the accompanying economic and population impacts increase the stress upon this land and its inhabitants. The close monitoring of the land and man's impact upon it is important with the greater demands being placed on the area by increased population, mining and energy production activities, and expansion of irrigation farming. The use of Landsat images of this area and the resulting land types derived from their study will assist planners in evaluating future impacts in this region.

CHAPTER III

EVALUATION PROCEDURES

Preliminary Classification

The photomorphic approach to land type study reduces the amount of field work which must be accomplished in conjunction with the evaluation. In preparation for the field sampling phase of this study, a preliminary study of Landsat coverage of a portion of the study area was conducted to determine the various color, tonal, and textural patterns which were represented. Four overlapping Landsat false color composite images were used for this evaluation (Figure 4).[1] These images were the most recent images of the area available for the same time of the year that the field work was planned. Imagery and ground truth sampling should be conducted as close to each other as possible because the physical appearance and image signature of many items, especially vegetation, change noticeably from season to season.[2]

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[1] The images used were obtained on 5 and 6 June 1975 and were Landsat image numbers 2134-17152; 2135-17204; 2135-17211; and 2134-17150.

[2] Sondra Wenderoth et al., Multispectral Photography For Earth Resources (Greenvale, New York: Remote Sensing Information Center, 1975), p. 79.

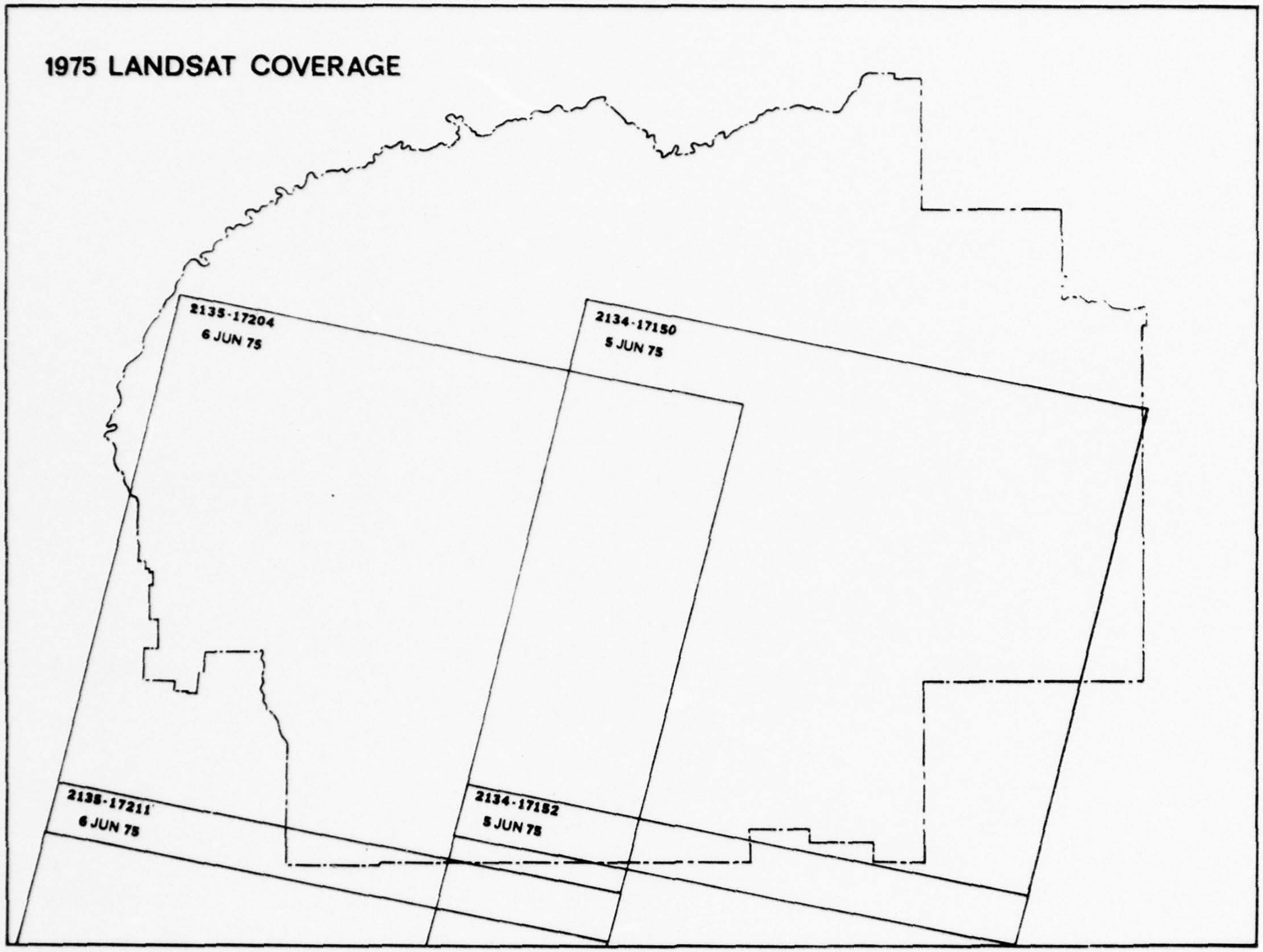
1975 LANDSAT COVERAGE
2135-17204
6 JUN 75
2134-17150
5 JUN 75
2135-17211
6 JUN 75
2134-17152
5 JUN 75

Figure 4

The images covered a major portion of the Reservations, specifically the area between 34°and 36°30' north latitude and 108°30' and 112°west longitude. Although not covering the entire study area, imagery was sufficient to allow the various colors which were present across the Reservations to be distinguished.

Through visual inspection of the images, in association with USGS topographic maps of the area, 36 different areas for detailed ground truth evaluation were identified. These areas were based on color, tonal and textural variations of the images and commonly recognized physiographic regions of the study area. Areas were selected to differentiate among differing image colors within the same physiographic regions (e.g. San Juan White, San Juan Blue and San Juan Tan) and the same image colors within different physiographic regions (e.g. Defiance Blue Green and Black Mesa Blue Green). The resulting 36 areas are listed in Table 1. The purpose of these areas was to serve as an initial guide to the field work in order that a representative number of samples would be gained from the various signatures occurring on the Landsat images.

Field Sampling

The purpose of the field sampling phase of this study was to determine what was located on the ground in the study area so that this information could be used to determine what combinations of terrain factors were responsible for

TABLE 1

PRELIMINARY SAMPLE AREAS AND NUMBER OF SUBAREAS IN EACH

Preliminary Classifications	Number of Subareas
House Rock	1
Escarpment Fringe (Moenave)	1
Light Blue Tan (Crooked Ridge)	1
Blue (Billy Goat Knolls)	2
Defiance Blue Green	3
Little Colorado White	4
Ganado Mesa	3
Kaibito Plateau	1
Black Mesa Red Brown	1
Black Mesa Blue Green	1
San Francisco Mts (Red)	1
Blue Light Tan (Crack in Rock Ruin)	1
Black (Black Point)	1
Paria Plateau	1
Defiance Red Mottled	2
Red Brown (Navajo N.M.)	2
Blue Green (Light)	1
Defiance Dark Blue Green	4
Gray Green (Church Rock)	1
Defiance Dark Red	3
Hopi Blue	4
Hopi Black (Buttes)	3
Hopi Brown	3
San Juan Tan	3
San Juan White	4
San Juan Blue	3
Chuska Brown	1
Chuska Dark Brown Mottled	3
Chuska Summit Dark Red	4
Chuska Tan	4
Chuska Pink	1
Chinle Valley Tan	5
Chinle Valley - Chuska Escarpment	1
Chinle Valley - Black Mesa Escarpment	2
Chinle Valley Blue	4
Defiance Red	3

the various color, tonal and textural signatures on the images. Field sampling was conducted during the month of June, 1976. Once in the field the 36 preliminary classifications were further broken down into from one to five subareas, depending on the areal extent and complexity of the initial areas. For example, Chuska Pink was detected in very small pockets along the summit of the Chuska Mountains, and therefore only one subarea for this preliminary classification was designated. However, areas such as San Juan White and Chinle Valley Tan were very extensive, and as many as four or five subareas of these regions were designated in order to achieve an adequate representation of the areas. Table 1 indicates the number of subareas within each of the preliminary classifications. These 83 subareas were identified as the areas within which field sampling would be conducted. The general location of these sample areas is shown in Figure 5.

Actual sampling sites within the 83 subareas were selected by determining the general location of the designated area on USGS topographic sheets of the area. Subsequently more detailed county highway maps were used to designate the actual sample site locations.[3] In order to obtain representa-

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[3] The county highway maps used in this study consisted of the Arizona State Highway Department, Photogrammetry and Mapping Division, Atlas of Apache County; Atlas of Coconino County; and Atlas of Navajo County; and the New Mexico State Highway Department Planning and Programming Division General Highway Map San Juan County; and McKinley County.

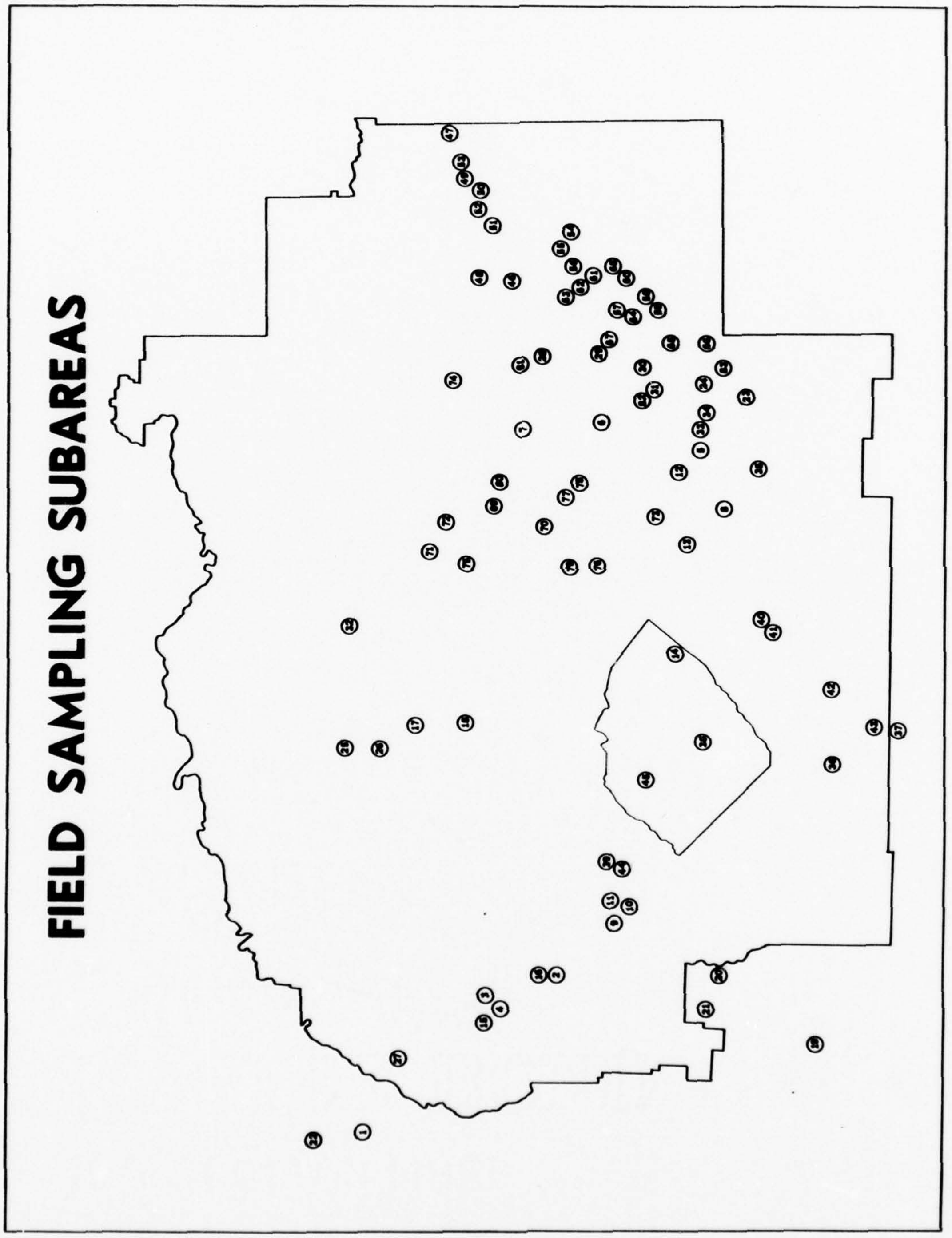

Figure 5

tive samples of each of the 83 subareas, 4 to 12 sample sites were selected in each subarea, resulting in the identification and analysis of 504 sample sites.

Sampling was conducted by six researchers working in teams of two. All researchers worked together on the first few sample sites to achieve uniformity of data collection. Additionally, the researchers divided into 3 groups of 2 to take the samples, but the groupings were changed periodically so that the sampling techniques remained consistent as the weeks of sampling continued. In another attempt to maintain consistency of sampling and to eliminate as much as possible researcher bias, the sample site locations were selected at the base camp prior to departing for a day's sampling activities. The subareas were delineated on the county highway maps and sample sites were located within the subareas so as to obtain a representative distribution of sample sites along routes through the subareas. Once a team reached the edge of a sample subarea, the vehicle odometer was noted. The distance to the first sample site was recorded and when this distance had been driven the vehicle was stopped. Sample sites were designated in pairs with each pair being perpendicular to the road in opposite directions and 50 paces from the road in order to avoid the effects of road maintenance and traffic.

Once the site was determined, a 50 foot steel tape was laid out perpendicular to the line of pacing, thus forming one

side of a 50 foot square which was the sample site. A 50 foot square was deemed to be of adequate areal extent to provide an accurate sample. Petier recommended these size areas for field measurements since they are small enough to be handled easily and present an essentially homogeneous area.[4] A sample site data sheet was completed for each site (Figure 6).

The first four items on the data sheet were reference items. Topo Quad referred to the USGS Topographic Map upon which the sample site was located. ERTS Image and Date referred to the Landsat image on which the sample site was located. Signature designated in which of the 83 subareas the sample site was located, Sample No. was the numeration of the sample site within the subarea. Elevation was measured to the nearest 100 feet from the USGS Topographic Sheet. Slope Orientation was measured according to the compass direction of slope. Landuse was based on the observed features in the area. Grazing was the major land use in the majority of the sample sites. Degree of Slope was categorized into one of the four classes on the form and if greater than 12 degrees the estimated degree of slope was indicated; other slope comments were also noted on the form. Geology was obtained from geologic maps of the area. Outcrop within the 50 foot square

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[4] Louis C. Petier, "Area Sampling for Terrain Analysis," in Climatic Geomorphology ed. Edward Derbyshire (London: The Macmillan Press Ltd, 1973), p. 193.

Topo Quad:________________ERTS Image & Date______________

Signature:__________________Sample No.__________________

Elevation(100ft)__________Slope Orient.__________________

Landuse____

Degree of Slope: 0-2_____2-7_____7-12____12+_____

Slope Comments____

____

GEOLOGY: formation and lithology__________________________

outcrop(% within site)___________________________________

SOIL: Depth(inches) Description(color & texture)

____________	________________________
____________	________________________
____________	________________________
____________	________________________

Origin:(residual, alluv., etc)____________________________

Erosion evidence:____

____

GROUND COVER: Plants(per 50 ft)_____Max Distance Between_____

Types of plants (Dia. of average/Height)__________________

Grass(If present note type & character)__________________

____

TREES:(Type/number/height)________________________________

____

____

Stumps(number/type)____________Seedlings Present__________

COMMENTS:

Figure 6. Sample Site Data Sheet

sample site was indicated as a percentage of the total sample area having bedrock at the surface. Using a soil auger, a description of the soil changes, and depths at which they occurred were determined down to bedrock or 18 inches. These items were recorded in the soil portion. An attempt was made to determine the origin of the soil and this was indicated along with comments on erosion evidence.

To determine the density of vegetation and grass cover, the number of plants along the 50 foot steel tape was counted and the maximum distance between plants was noted. The plants were identified and the average diameter and height of the dominant species were measured. If grass was present, the type and character was noted. All trees within the 50 foot square sample site were counted and identified by species. The tallest of each species was measured and height indicated. If stumps were present, it was so indicated. Further, tree seedlings were noted according to species. Any additional comments pertaining to the sample site were added at the bottom of the form. For enumeration purposes a height of 6 feet was used to differentiate between trees and seedlings. Figure 7 lists the vegetation species which were identified in this study.[5]

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[5] This list is by no means a complete list of the vegetation types and species found in this area. For example, Little has identified over 132 different species of trees alone in the states of New Mexico and Arizona. The purpose of this study is to describe land types based on dominant vegetation considered along with other factors. For this purpose the list of vegetataion types in Figure 7 is sufficient. U.S. Department of Agriculture Southwestern Trees A Guide to the Native Species of New Mexico and Arizona, by Elbert L. Little, Jr., Agriculture Handbook No. 9 (Washington, D.C.: Government Printing Office, 1950), p. 2.

Grasses	Shrubs	Forbs	Trees
Undifferentiated	Sagebrush	Yucca	Juniper
Gramagrass	Morman Tea	Asters	Pinyon
Crested Wheatgrass	Rabbitbrush	Agave	Ponderosa Pine
	Saltbrush	Snakeweed	Cottonwood
	Greasewood	Skunkweed	Oak
Cacti	Bearberry	Tumbleweed	Aspen
Undifferentiated	Wolfberry	Wildflowers	Salt Cedar
Pricklypear	Creosotebush	Undifferentiated Herbs	Douglas Fir
Cholla	Buffaloberry	Poison Ivy	Spruce
Barrel	Skunkbush	Ferns	Poplar
Strawberry	Serviceberry	Dandelions	Maple
Pincushion	Shadscale	Wild Iris	Boxelder
Fishhook	Mountainmahogany	Daffodils	Willow
	Cliffrose		

Figure 7. Vegetation species identified in the study

Photomorphic Mapping

Landsat coverage of the study area which was obtained was conducted during the same time frame as the field sampling. This consists of 7 overlapping Landsat images which were taken on 25, 26 and 27 June 1976[6] (Figure 8). These images completely cover the study area except for two small areas along the southern border of the study area which were evaluated from the images used in the preliminary evaluation. These images were the ones to which the photomorphic mapping procedure was applied.

Using a standard photographic enlarger and working in a darkroom, the Landsat false color composite transparencies were projected onto the USGS topographic sheets of the study area so that the images were enlarged to the same scale as the topographic sheets (1:250,000). A sheet of white drawing paper was then placed over the topographic sheet, and the different color, tonal and textural patterns of the images projected onto the paper were delineated. The Landsat imagery is a perspective-plane projection of the curved surface of the Earth and therefore somewhat distorted. The USGS map sheets are cast on the Universal Transverse Mercator (UTM) projection. This difference caused no significant problem with the enlargement and projection. In a study comparing Landsat imagery to

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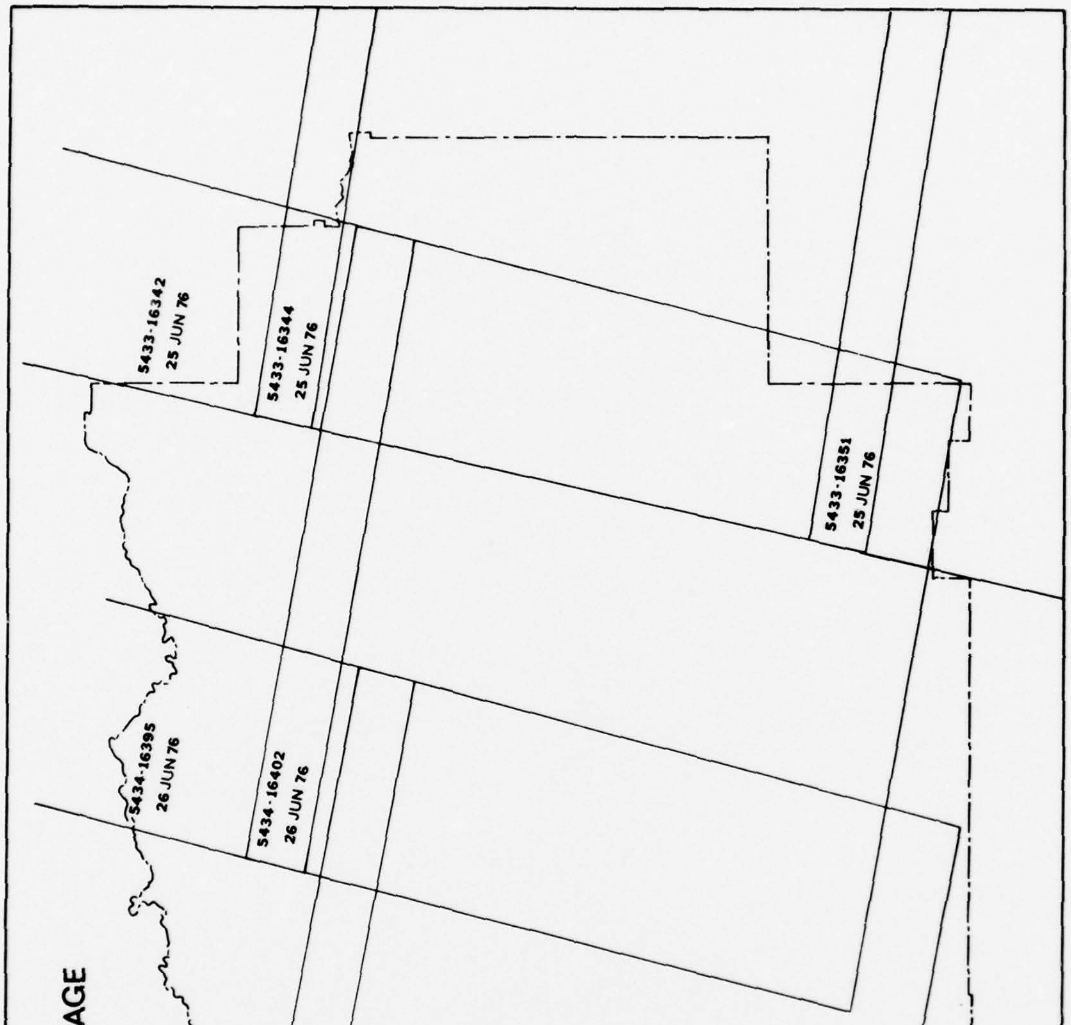
[6] These images consist of Landsat image numbers 5433-16351; 5433-16344; 5433-16342; 5434-16402; 5434-16395; 5435-16460; and 5435-16453.



1976 LANDSAT COVERAGE
5433·16342
25 JUN 76
5433·16344
25 JUN 76
5433·16351
25 JUN 76
5434·16395
26 JUN 76
5434·16402
26 JUN 76
5435·16453
27 JUN 76
5435·16460
27 JUN 76

Figure 8

UTM maps, Colvocoresses identified five errors that affect the geometry of the Landsat image. These errors were earth curvature, atmospheric refraction, camera obliquity, terrain relief, and map projection error.[7] His report indicated that even the combined effect of all of these errors was small enough to be disregarded in most studies. Kratky, in a similar study, determined that although there is a slight curvature in the individual scan lines on the imagery, again due to earth curvature, it is too small to be detected in most studies.[8]

Colvocoresses suggests that the best means of achieving accuracy between the Landsat imagery and the UTM map sheets is by "controlling the imagery to identifiable points on the ground."[9] This control was utilized in the present study. Working with sections thirty minutes in latitude and longitude and using triangulation of at least three identifiable points on the images and on the map sheets, errors due to differences between the two projections were reduced. Mountain peaks, buttes, mesas, canyons, volcanic necks, lakes and rivers alike displayed distinctive enough signatures on the

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[7] Alden P. Colvocoresses, "ERTS-A Satellite Imagery," Photogrammetric Engineering 36 (June 1970): 556-559.

[8] V. Kratky, "Cartographic Accuracy of ERTS," Photogrammetric Engineering 40 (February 1974): 212.

[9] Colvocoresses, p. 555.

Landsat images to allow them to serve as known location points for reference purposes.

The problem of classification schemes and categories in studies of this type is a much discussed topic.[10] Some researchers feel that a uniform classification scheme which is both general and specific and applicable to all environments and at all scales is the solution.[11] However, others hold to the idea put forth by Grigg that each classification should be developed for a special purpose, and that general purpose classifications should be discouraged.[12] The land type classification developed in this study is of the

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[10] Nelson R. Nunnally, "Interpreting Land Use From Remote Sensor Imagery," in Remote Sensing Techniques for Environmental Analysis, ed. John E. Estes and Leslie W. Senger (Santa Barbara: Hamilton Publishing Company, 1974), p. 168. See also Robert E. Brown and Robert K. Holz, "Land-Use Classification Utilizing Infrared Scanning Imagery," Photogrammetric Engineering and Remote Sensing 42 (October 1976): 1303-14; Nelson R. Nunnally and Richard E. Witner, "Remote Sensing for Land-Use Studies," Photogrammetric Engineering 36 (May 1970): 449-53; and James R. Anderson, "Land-Use Classification Schemes," Photogrammetric Engineering 37 (April 1971): 379-87.

[11] William G. Brooner and David A. Nichols "Considerations and Techniques for Incorporating Remotely Sensed Imagery Into the Land Resource Management Process" in Remote Sensing of Earth Resources ed. F. Shahrokhi (The University of Tennessee: Tullahoma Tennessee Space Institute, 1972), p. 7. An example of an attempt at a general purpose land classification scheme can be found in James R. Anderson et al., A Land Use and Land Cover Classification System for Use with Remote Sensor Data, Geological Survey Professional Paper 964, Washington, D.C., 1976.

[12] R.J. Johnston, "Grouping and Regionalizing: Some Methodological and Technical Observations," Economic Geography 46 (June, 1970): 293.

latter type and was developed specifically for the Landsat coverage of the study area. It is based entirely upon color, tonal and textural classes found within the study area itself. As Anderson has stated, an integral part of any mapping of this nature is "the selection of a suitable classification scheme for use at a specified scale, for a designated area, and within the capability of the information gathering techniques being used."[13] Another factor which enters into the decision on land type classifications includes the tradeoff between what has been called recognizability and reproducibility.[14] The recognizability of a land type is the proportion of it which can be recognized out of the area it covers by means of the tools and resources being utilized. In the case of the current study, this would mean the distinct land type classes that can be identified projecting the images to the scale of 1:250,000. Reproducibility, on the other hand, is the extent to which the properties of the terrain can be identified in terms of landforms, vegetation, and the like. These two factors are inversely related such that the more carefully the land types are defined, the more difficult they will be to recognize and

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[13] James R. Anderson, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data," p. 379.

[14] Colin W. Mitchell, Terrain Evaluation (London: Longman Group Limited, 1973), pp. 10-11.

the more types there will be. The answer is to not define the types beyond the point at which they are generally recognizable.[15]

With the Landsat images of the study area enlarged on the photographic enlarger it was possible to identify a total of 19 different land type classes based on the color, tonal and textural signatures of the images. These classes were identified and mapped over the entire study area. Image 5434-16402 was established as the base image against which the color variations of the other images were compared. Although taken within three days of each other, the images did display subtle differences in color due possibly to changing atmospheric conditions or differences in processing such that one image was used as a standard against which to compare the other images. Since there was an overlap between the various images it was possible to move from one image to another in mapping and compensate for the differences in color.

The nineteen color, tonal and textural classes make up the land type classes which were identified in the study area. For this reason the land type classes were named, in all but one case, according to the distinctive color or color and texture for that land type. The "pure" color land types which were identified consisted of Tan, Light Blue, White, Red, Blue Green, Olive, and Brown. Tonal variations and color

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[15] Ibid., p. 11.

combinations comprised the color classes of Dark Tan, Light Blue Tan, Tan Brown, Red Brown, Brown/Blue Green and Chuska Summit. The latter class was so named because of its distinct location along the summit areas of the Chuska Mountains. Its colors consisted of mixed red, pink and green. The classes which were identified also by texture were Brown Tan Rugged, Light Blue Tan Rugged, Light Blue Rugged, Brown Mottled, Blue Green Mottled and Hopi Blue. Hopi Blue displayed a distinct pattern of mesas within the general blue color area. Two other categories were identifiable on the images and mappable. Water, in lakes and rivers, displayed a distinct pattern of either black or deep blue depending upon the depth and sediment content. Irrigated farming areas could be identified by their regular shape and very brilliant pink and red coloring. The land type classes and the abbreviations used to identify them are listed in Table 2.

After the study area had been mapped using the 19 land type classes, irrigated farm areas and water features, the location of the 83 sample subareas were indicated and the land type class for each subarea was noted (See Table 2). The sample site data sheets for each land type were assembled, and the geographic description of each land type was compiled based on analysis of the data sheets. The land type map of the study area and description of the different land types resulted. The land type maps are located in the Appendix, and the description of each land type is contained in Chapter Four.

TABLE 2

LAND TYPE CLASSES, MAPPING DESIGNATORS AND SAMPLE SUBAREAS CLASSIFIED WITH EACH LAND TYPE CLASS

Land Type	Mapping Designator	Sample Subareas
White	1	51
Light Blue	2	32, 69, 73, 77
Tan	3	1, 2, 8, 9, 16, 46, 47
Dark Tan	4	10, 11, 39, 44
Light Blue Tan	5	3, 27, 36, 37, 38, 43 48, 49, 50, 52, 53, 54 55, 70, 71, 72, 78, 79
Light Blue Rugged	6	75, 76
Light Blue Tan Rugged	7	45
Brown Tan Rugged	8	74, 80
Hopi Blue	9	40, 41, 42
Tan Brown	10	7, 14
Brown	11	33, 34
Brown Mottled	12	12, 13, 56, 58
Blue Green	13	5, 6, 18, 21, 22, 28, 30, 31, 35, 57, 64, 65, 66
Blue Green Mottled	14	20
Olive	15	4, 15
Brown/Blue Green	16	17, 25, 26
Red Brown	17	23, 24, 29, 59, 60, 67, 81, 82, 83
Red	18	19, 62
Chuska Summit	19	61, 63, 68
Water	20	
Irrigated Cropland	21	

Quantitative Analysis

Although the sample site data sheets were primarily subjective in nature, several quantitative items were included on the forms. These variables were used in a statistical analysis of the relationships among the various variables and of the role of particular variables in discriminating among groups of the land type classes. The variables extracted or derived from the data are listed in Table 3. The mean values for each variable in each of the 83 sample subareas were determined and used in the data analysis. It should be pointed out that the variables selected do not give a complete description of the sample sites. For example, soils and geology are not represented and vegetation parameters comprise the majority of the variables used.

Because of the strong orographic effects on climate and vegetation within the study area, elevation was selected as a critical variable in the analysis. Simple correlation coefficients between elevation and all the other variables are shown in Table 4. The correlation between elevation and tree height shows the strongest relationship; the greatest height of vegetation and total tree density were also highly correlated. Interrelationships among the variables are also important. For example, greatest tree height and greatest height of vegetation are highly related ($r = 0.99$) as are greatest height of vegetation and total tree density ($r = 0.791$).

The relationship of each of the other variables to

TABLE 3

VARIABLES USED IN THE QUANTITATIVE ANALYSIS

Elevation

Slope

Percentage outcrop

Plants per 50 feet

Maximum distance between plants

Greatest height of vegetation

Number of tree types

Total tree density

Greatest tree height

Number of pinyon

Number of juniper

Number of ponderosa pine

Greatest height of shrubs

TABLE 4

SIMPLE CORRELATION COEFFICIENTS BETWEEN ELEVATION AND THE OTHER VARIABLES

Slope	0.148
Percentage Outcrop	0.102
Plants/50 feet	0.542*
Maximum distance between plants	-0.275*
Greatest height of vegetation	0.698*
Number of tree types	0.560*
Total tree density	0.626*
Greatest tree height	0.700*
Number of pinyon	0.274*
Number of juniper	0.208
Number of ponderosa	0.536*
Greatest height of shrubs	-0.168

*Significant at the .05 level.

elevation was analyzed via stepwise multiple regression[16] (Table 5). The relationship studied took the form

$$Y = a + b + E + c\ E^2$$

where Y is the measured variable and E is the elevation.[17] The results shown are for the best fitting step determined on the basis of contribution to explained variance (R^2) and this determined whether the linear or the quadratic equation provided the best fit for the data. The results for all but one of the variables (percentage of outcrop) were significant at the .05 level or higher; R^2 values ranged from 7 to 52 percent. Six of the relationships took on a linear form. As would be expected, the number of plants per 50 feet increased linearly with increasing elevation, whereas the maximum distance between plants (an inverse measure of plant density) decreased linearly with elevation. The number of tree types and the total tree density per sample site also increased linearly with elevation as did the greatest height of vegetation and the greatest tree height. The remaining variables were best explained by the quadratic equation. Some variables attain a maximum or minimum value within the range of elevations

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[16] The program BMDO2R was utilized. W.J. Dixon, ed., Biomedical Computer Programs (Berkeley: University of California Press, 1970), pp. 233-57.

[17] Using transgeneration the intercept for the elevation variable was shifted to 5000 feet since this is approximately the lowest elevation of all the sample subareas. The equation therefore describes a best fitting curve for the elevations in the study area.

TABLE 5

REGRESSION RESULTS

	Intercept	Elevation	$(\text{Elevation})^2$	F	R	Elevation at Inflection Point
Slope	2.195	4.261** (3.415)	-0.972** (9.689)	3.172*	0.271	7192
Percentage outcrop	-0.072	0.289* (2.052)	-0.052** (3.626)	0.587	0.120	7779
Plants/50 feet	9.958	13.957** (13.969)		33.624**	0.542	
Maximum discance between plants	13.227	-2.372** (7.175)		6.615**	0.275	
Greatest height of vegetation	-6.127	16.902** (39.935)		76.949**	0.698	
Number tree types	0.002	0.756** (298.75)		37.045**	0.560	
Total tree density	-1.550	3.203** (117.99)		52.269**	0.626	
Greatest tree height	-7.869	17.423** (39.446)		77.880**	0.700	
Number of pinyon	-1.328	3.056** (13.299)	-0.639** (31.686)	7.259**	0.392	7391
Number of juniper	-0.368	1.276** (38.975)	-0.292** (111.74)	7.148**	0.389	7185
Number of ponderosa	0.174	-1.118* (2.619)	0.741** (62.780)	25.219**	0.622	5754
Greatest height of shrubs	1.349	1.222** (23.888)	-0.399** (139.22)	8.657**	0.422	6531

Numbers in parentheses are t-values
*Significant at the p = .05 level
**Significant at the p = .01 level

in the data set (Table 5).[18] For example, slope increases with elevation up to about 7200 feet and then decreases. Likewise, the density of pinyon and juniper trees increases with elevation up to about 7400 and 7200 feet, respectively, where their densities begin to decrease. The density of ponderosa pine, on the other hand, has a minimum value at about 5750 feet and then increases at an increasing rate. These values are all in keeping with the concept of zones of vegetation in this area which are based on elevation.[19] Actual sample subarea values for each of the variables and the best-fitting curve for the relationship are shown in Figures 9 through 20.

The nineteen land type classes were divided into four groups based on suspected association of the various classes (Table 6). Group 1, or SAGE, consisted of the land type classes associated with the basin areas and poorly vegetated portions of the study area. Group 2, or RUGGED, was made up of the land type classes in which texture was a major factor. Group 3, JUNPIN, consisted of the land types asso-

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[18] The elevation at which the minimum or maximum is attained is determined by differentiating $Y = a + bE + cE2$ with respect to E yielding $b + 2cE$ and solving for E. Thus substituting the estimated regression coefficients in the term b/2c gives the elevation at the inflection point for each variable.

[19] U.S., Department of Agriculture, Southwestern Trees A Guide to the Native Species of New Mexico and Arizona, by Elbert L. Little, Jr., Agriculture Handbook No. 9 (Washington, D.C.: Government Printing Office, 1950), pp. 5-7

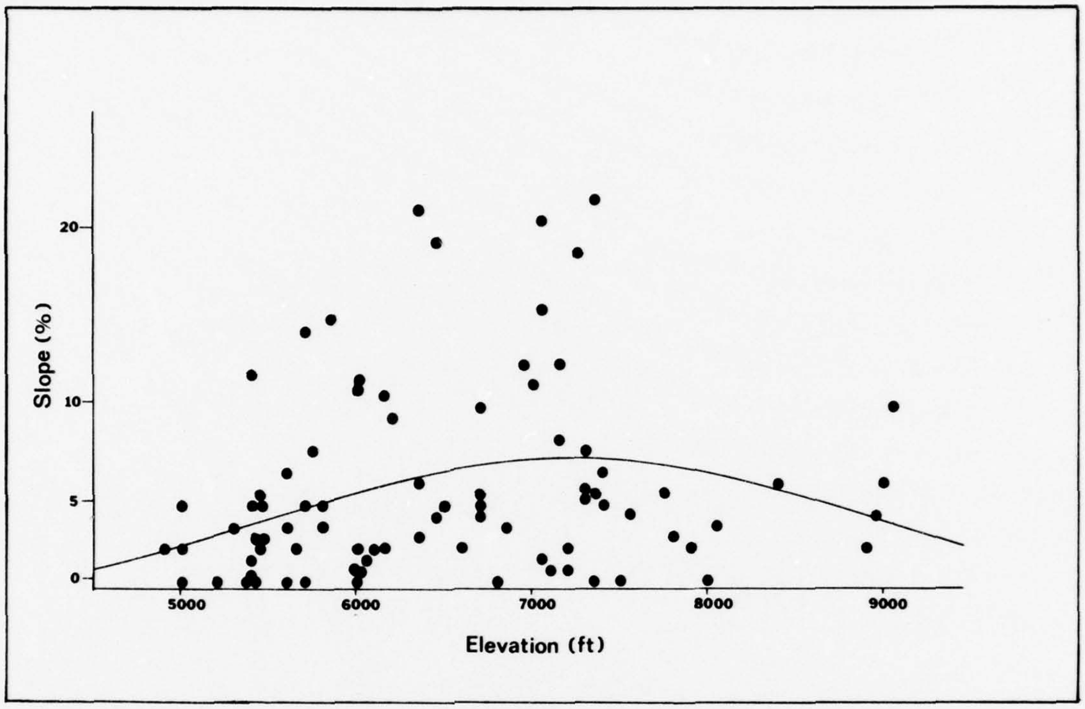
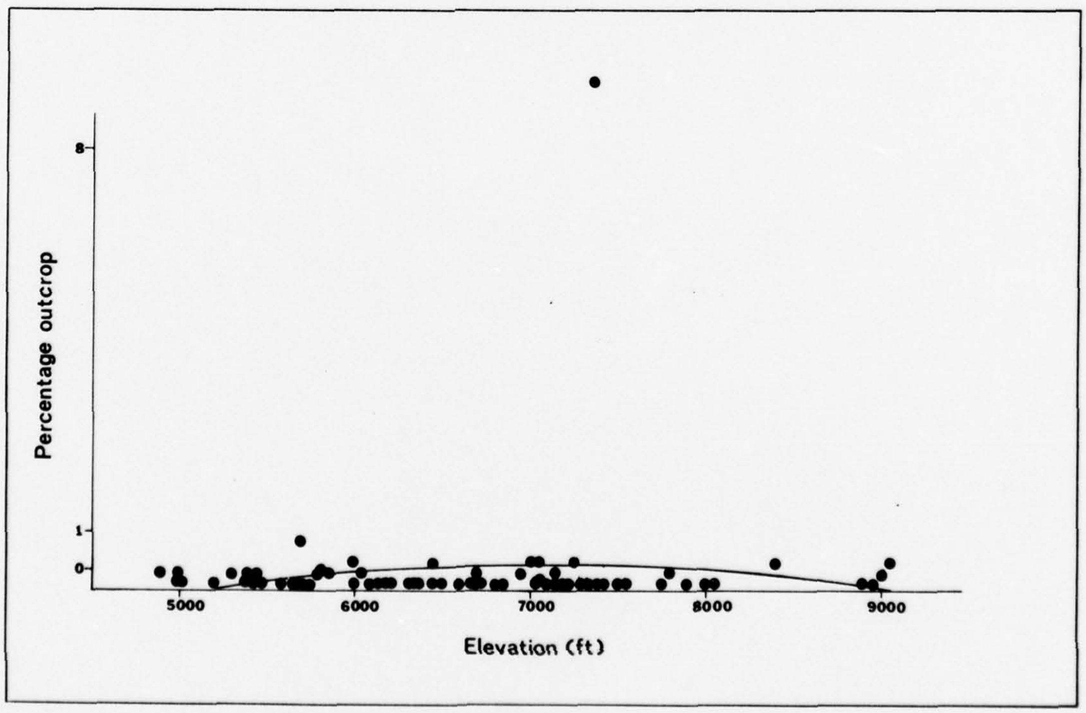


Figure 9



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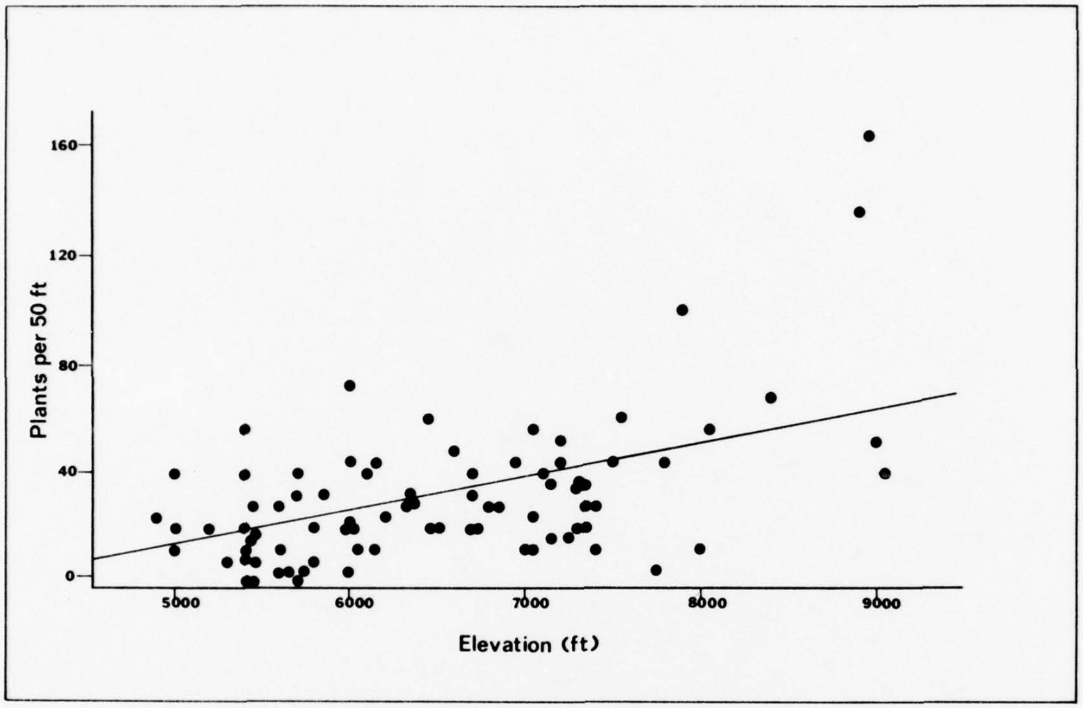

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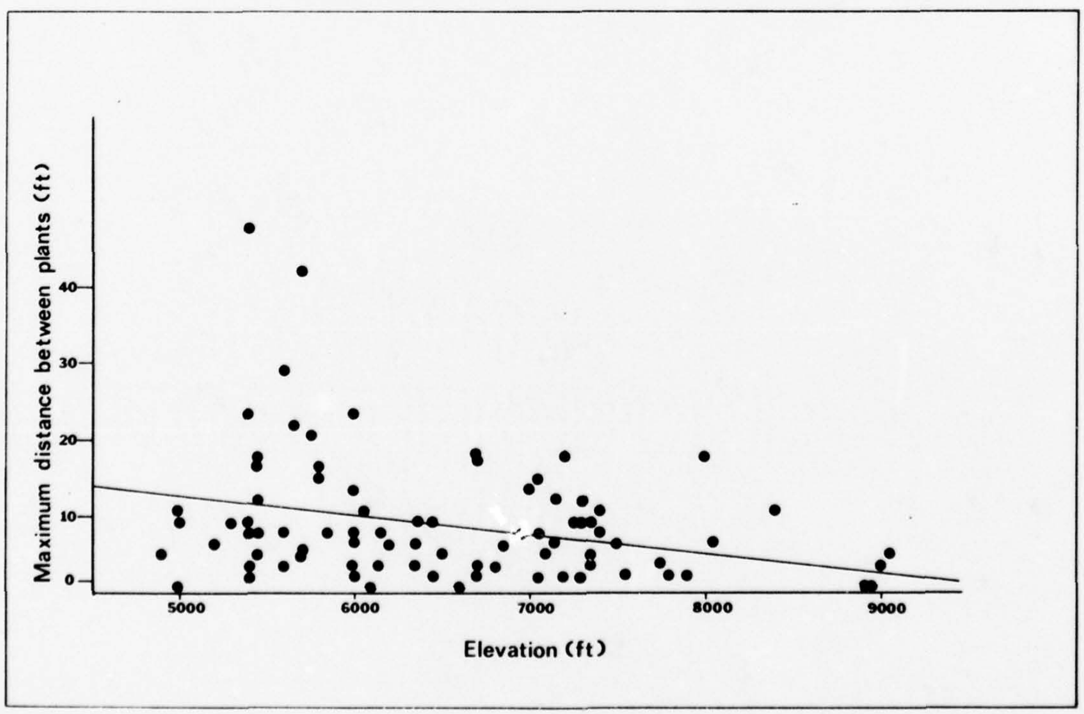

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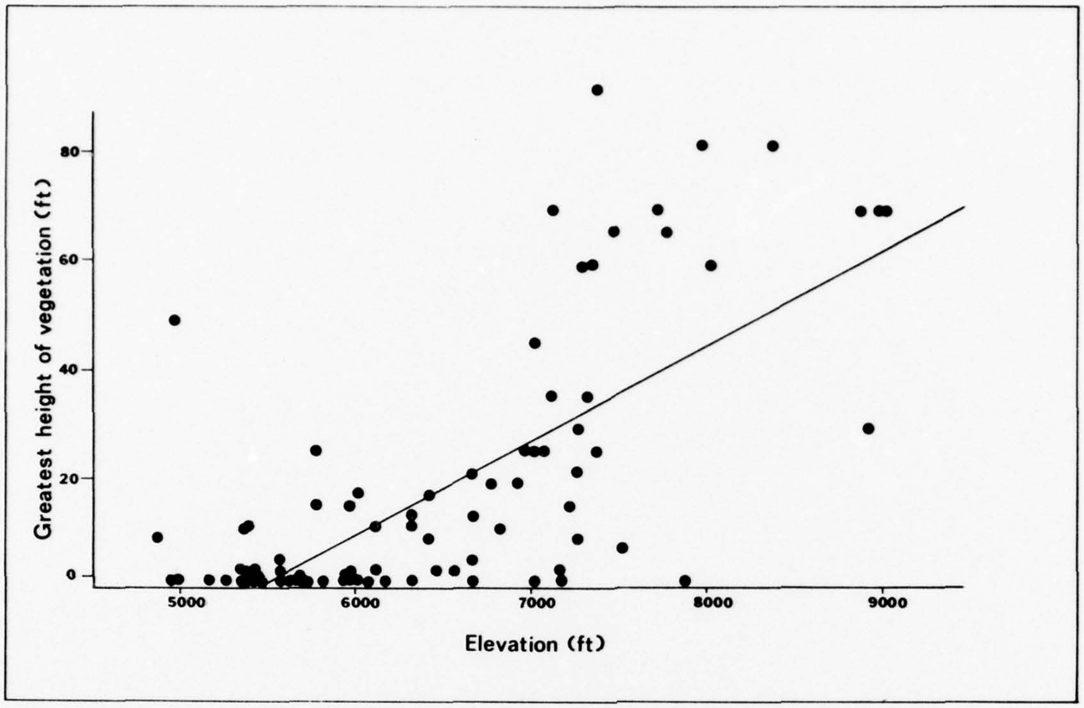

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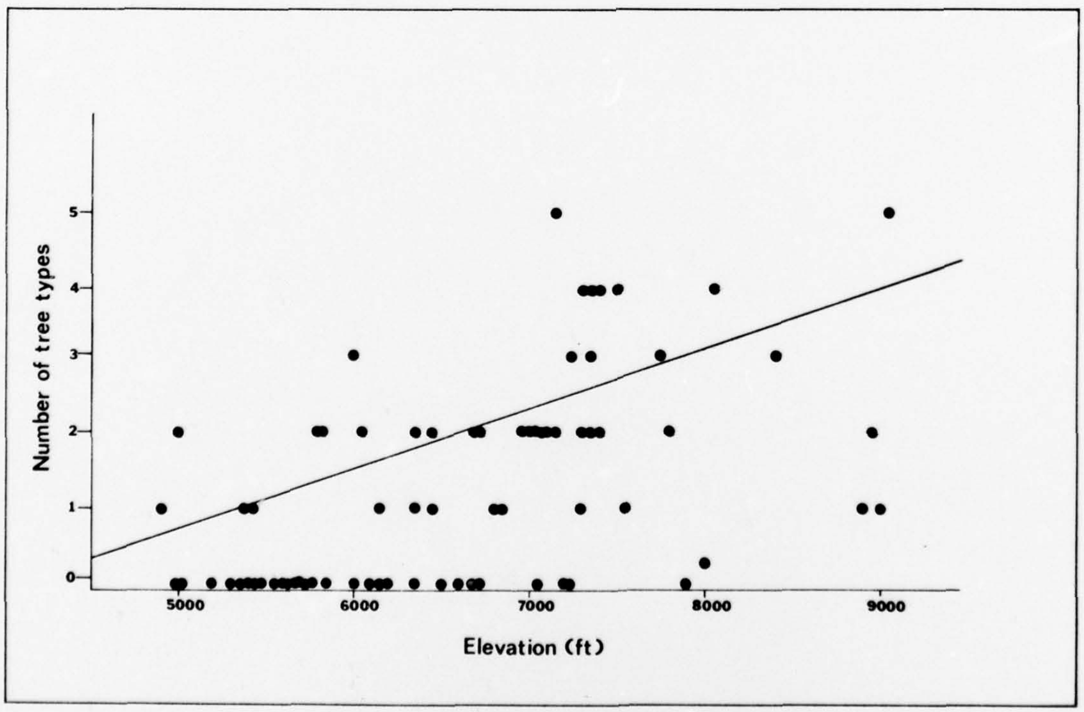

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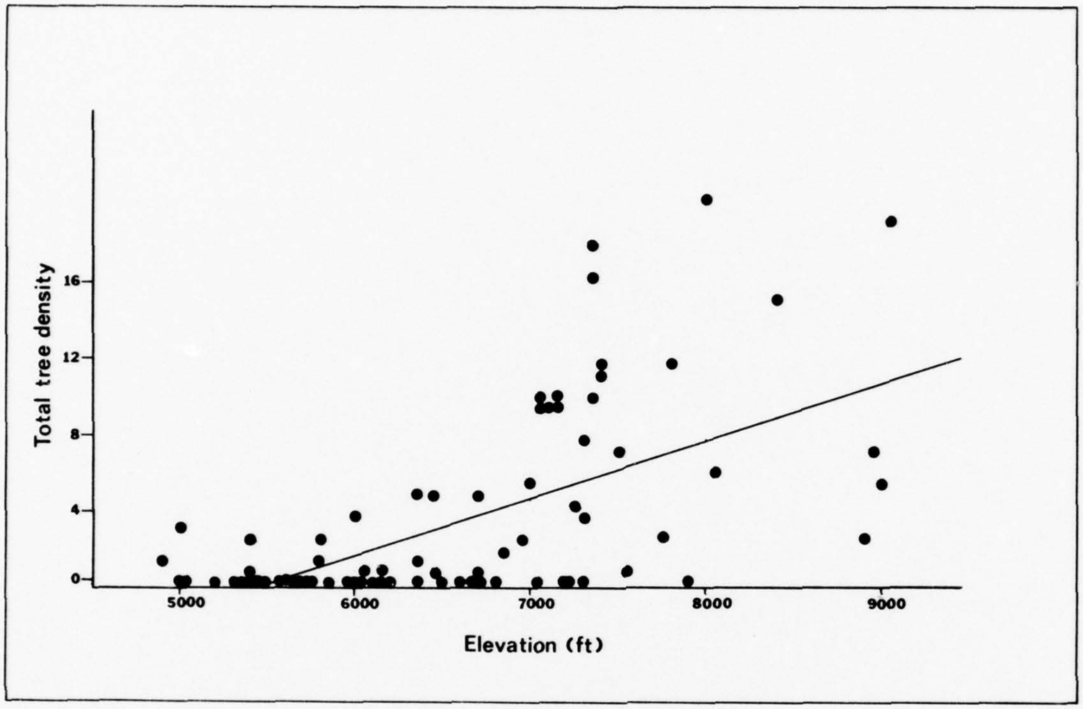

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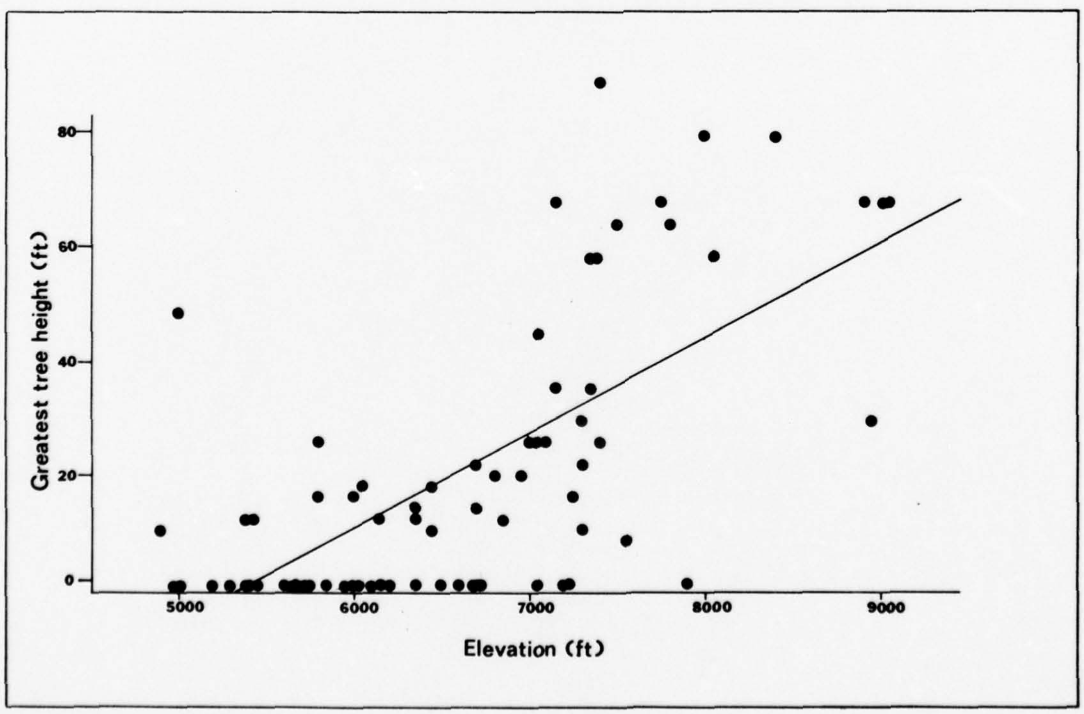
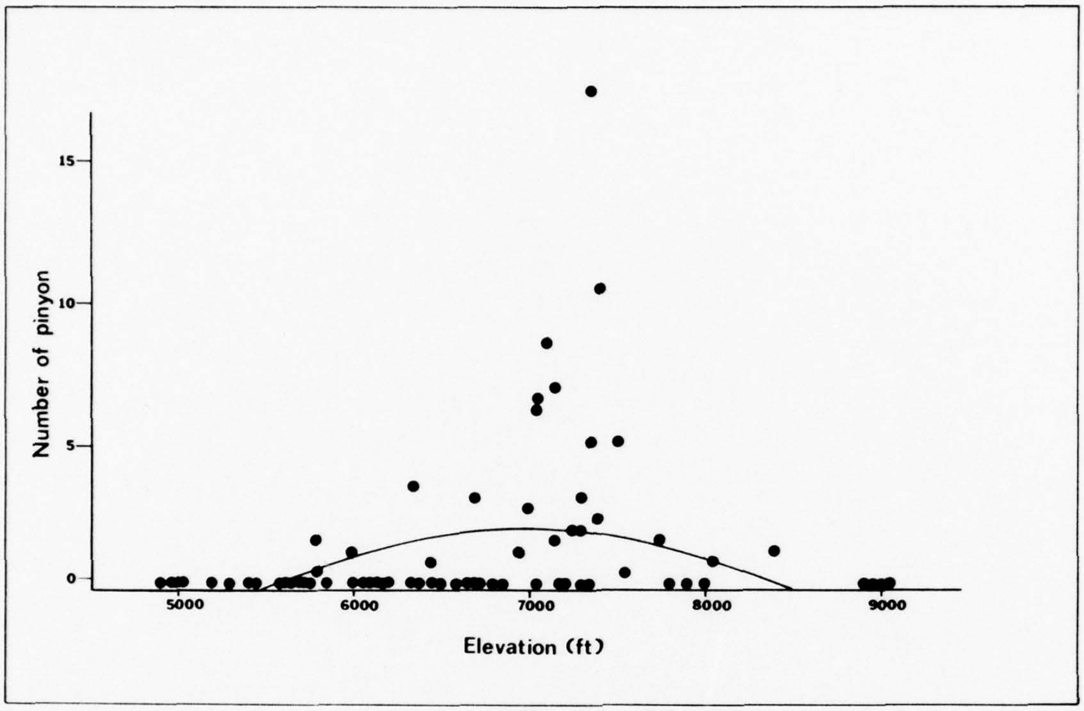


Figure 16



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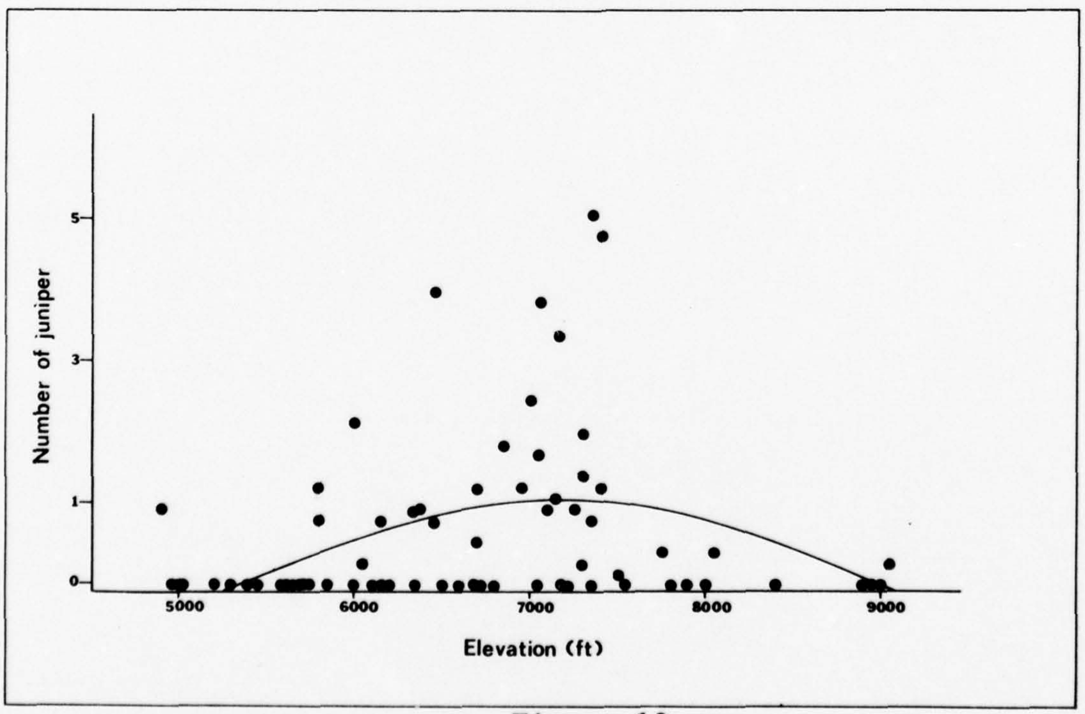

Figure 18

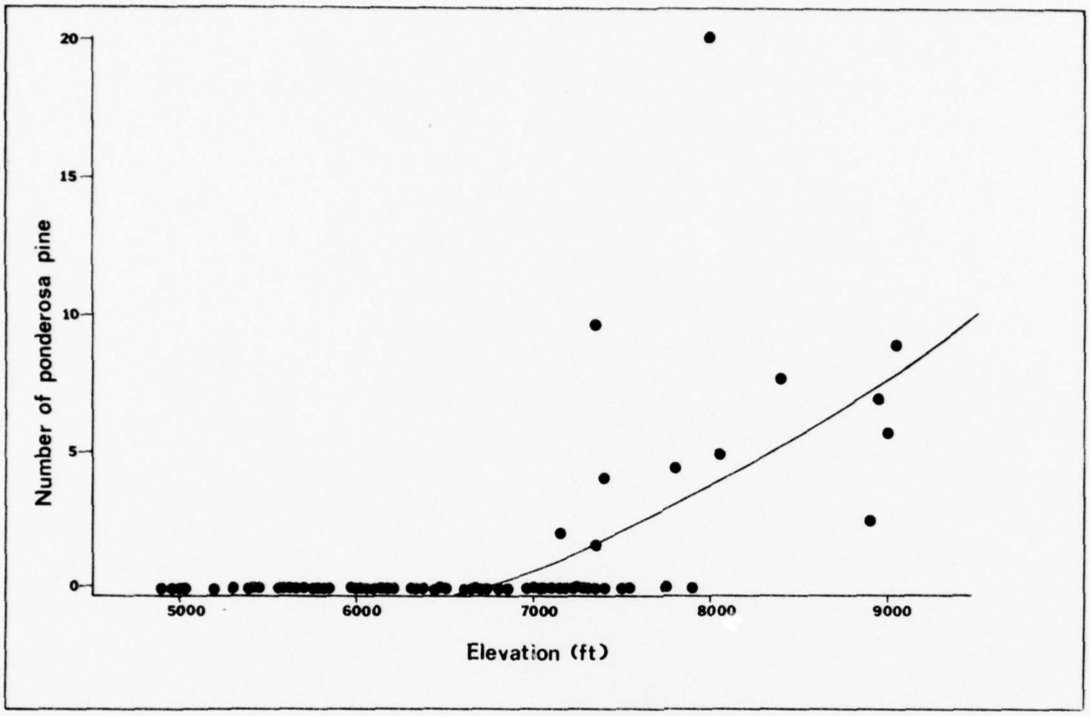

Figure 19

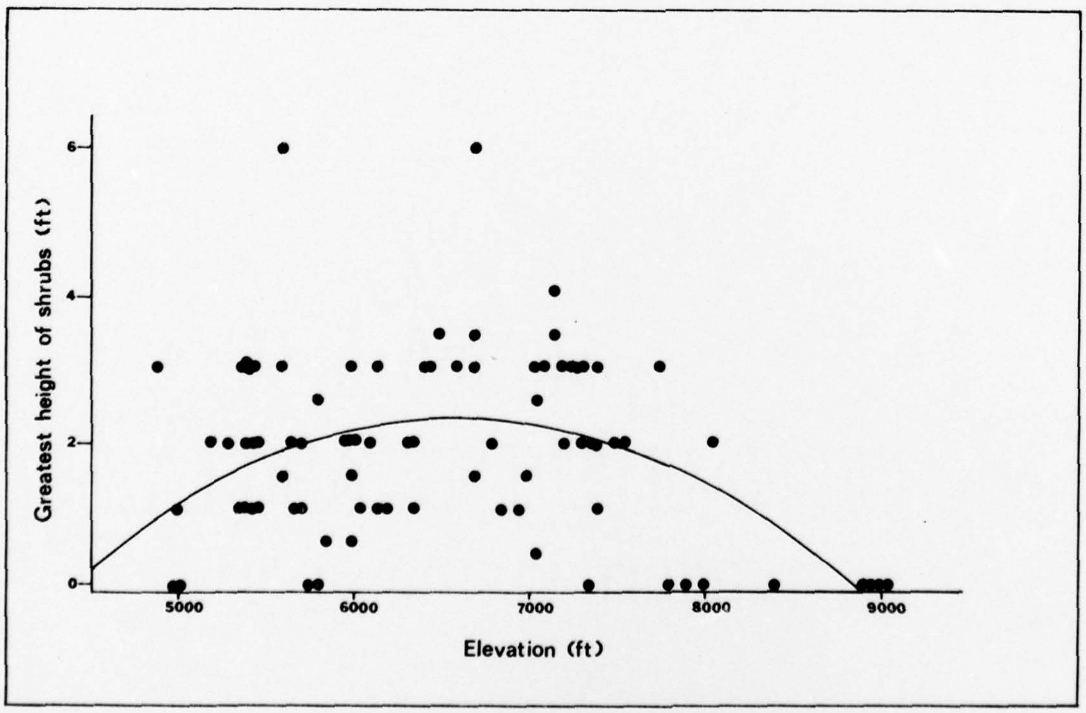

Figure 20

TABLE 6

GROUPS OF LAND TYPE CLASSES

Group	Land Type Classes
Group 1 - SAGE	White Light Blue Tan Dark Tan Light Blue Tan
Group 2 - RUGGED	Light Blue Rugged Light Blue Tan Rugged Brown Tan Rugged Hopi Blue
Group 3 - JUNPIN	Tan Brown Brown Brown Mottled Blue Green Blue Green Mottled Olive Brown/Blue Green
Group 4 - PINE	Red Brown Red Chuska Summit

ciated with the intermediate vegetation zones between the sparse lower elevation areas and the higher pine-forested areas. Group 4, PINE, was associated with the higher elevations and forested areas.

A stepwise discriminant analysis was used to determine if the four groups could be distinguished on the basis of the thirteen variables and which of the variables particularly characterize the differences among the various groups.[20]

Initially all thirteen variables were included in the analysis (Table 7). However, only the first five variables which entered the discriminant function were significant on the basis of their F-values. The role of particular variables in discriminating among the groups is indicated both by the simple F-statistics and the final partial F-statistics that consider all other variables. The five variables were successful in distinguishing among the land type groups. The overall F-statistic, which indicates the discriminatory power of the function, is significant at the .01 level. Elevation was the first variable to enter the stepwise function and was successful in discriminating all four groups of land type classes. Slope was most significant in identifying the RUGGED group from the other groups. Percentage outcrop and the number of ponderosa separated the PINE group from the

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[20] The program BMD07M was utilized which performs a forward stepwise discriminant analysis. Dixon, pp. 214a -t.

TABLE 7

CRITICAL VARIABLES FOR DISTINGUISHING LAND TYPE GROUPS

Variables	Simple F	Final F
Elevation	45.84**	21.80**
Slope	11.17**	10.93**
Percentage Outcrop	1.73	3.92*
Plants/50 feet	7.51**	
Maximum distance between plants	2.14	
Greatest height of vegetation	32.16**	
Number of tree types	12.90**	
Total tree density	17.53**	
Greatest tree height	32.10**	
Number of pinyon	5.17**	
Number of juniper	6.16**	5.77**
Number of ponderosa	24.93**	10.89**
Greatest height of shrubs	6.14**	
Overall F Statistic		14.94** (df = 5,75)
Percentage correctly classified		79.5%
(Percentage expected from Random Assignment)		(25%)

* Significant at the p = .05 level

** Significant at the p = .01 level

others and the number of juniper was most successful in discriminating the JUNPIN group.

These five variables accounted for 79.5 percent of the sample subareas being classified into the correct group (Table 8). This compares favorably against the 25 percent correct classifications which would result from random assignment of the subareas. On the basis of the Chi-square test the classification from the discriminant analysis was not significantly different from the actual classification (where all values in Table 8 would be along the diagonal).[21]

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[21] The Chi-square statistic for this classification is determined by summing the (observed-expected)^2/ expected classifications for each of the four groups. For the Chi-square to be significant at the .05 level it would have to have a value of over 40. The computed value for these results is 3.7, clearly not significant. This means that the predicted classification using the five variables is not significantly different from the actual classification of the sample subareas.

TABLE 8

SAMPLE SUBAREAS CLASSIFIED INTO GROUPS

Group	1. SAGE	2. RUGGED	3. JUNPIN	4. PINE	Percent correctly classified
1. SAGE	29	4	1	0	85.3%
2. RUGGED	2	6	0	0	75.0%
3. JUNPIN	4	2	21	0	77.8%
4. PINE	0	0	4	10	71.4%
				Overall	79.5%

CHAPTER IV

THE LAND TYPE CLASSES

The nineteen land type classes derived from this study are displayed on the land type maps of the study area contained in the Appendix. The purpose of this chapter is to give a brief description of each of the land type classes, their photomorphic appearance, geographic location and terrain measurements that differentiate the various land types from one another. The four sets of land types which were discussed in the quantitative analysis section are described and then subdivided into the land type classes that are based on the photomorphic appearance of the Landsat signatures. Elevation, a critical variable in differentiating the groups of land types, was also a factor in discriminating the sample sites into the various land type classes. Vegetation is responsible for the differences between many of the classes, with slope and soils associated with bedrock geology causing different image signatures in some cases.

Group 1 Land Types (SAGE)

These land types occur at lower elevations primarily below 5800 feet. They extend over the San Juan Basin, Chinle Valley, Monument Valley, Moenkopi Wash and lower elevations of the Hopi Buttes area. Grass is very sparse and the pre-

dominant vegetation is saltbrush, mormon tea, and greasewood. Sagebrush is found in areas associated with deeper, more moist soils, and cacti and yucca also are found in the area.

Land Type White

This land type, which displays a very uniform white appearance on the Landsat images, occurs in small areas in the San Juan Basin and Painted Desert areas, with the largest extent being along the Chaco River. It usually grades into areas of Tan or Light Blue Tan. Of the Group 1 land types the sample sites for these areas had the lowest elevations; around 5475 feet. The soil tends to be loose light-colored alluvium with high sand content. The vegetation cover consists of sparse, widely scattered saltbrush and mormon tea less than 2 feet high. This area has the lowest plant density per sample of any of the Group 1 land types.

Land Type Tan

Displaying a uniform tan appearance on the Landsat images, this land type appears extensively over all areas in which Group 1 land types are found (Figure 21). It generally grades into the Light Blue Tan areas. Elevations are only slightly higher than in the White, with a mean elevation of 5660 feet. The soils are sand and silt in association with sandstone and alluvial deposits. Areas of extensive dunes are also associated with this land type. Very sparse clumps of grass on deflation mounds along with low growths of saltbrush, greasewood and mormon tea prevail. Cottonwood and

Figure 21. Land Type Tan (Sample subarea 16, on the Kaibito Plateau east of Tuba Butte)

Figure 22. Land Type Light Blue Tan (Sample subarea 55, in the San Juan Basin west of Sheep Springs)

willow trees occur in isolated water rich areas along Moenkopi Wash.

Land Type Light Blue

Displaying a consistent light blue on the images, this land type occurs in narrow strips along washes in the Group 1 locations. Elevations are similar to those of the Tan class. This land type occurs near Tan and Light Blue Tan areas, but also can be found in washes at the base of slopes from Groups 2 and 3. These areas are primarily badlands, and soils, when present, are lithosolic. This land type is distinguished by an absence of sagebrush with the predominant vegetation consisting of greasewood, rabbitbrush, saltbrush and salt cedar.

Land Type Light Blue Tan

An overlay of light blue and shades of tan identify this land type on the images. This is the most extensive of the Group 1 land types and covers broad expanses of the lower elevations of the study area (Figure 22). Elevations are slightly higher than the previously discussed Group 1 land types with mean elevation of about 5750 feet. Surface soils are sandy ranging from light tan to reddish browns. Many areas are littered with rock fragments and comprised of weathered bedrock. This is the most prevalent and the typical Group 1 land type. This land type displays all of the lower elevation vegetation types with sagebrush, mormon tea, rabbitbrush and saltbrush prevailing. The shrubs in this area are small and widely

scattered with an average height of two to three feet. Cacti and yucca also occur in this area.

Land Type Dark Tan

These areas occur only in the western lower elevation areas of the study area in the Moenkopi Wash area and along the Moenkopi Plateau (Figure 23). The samples in these areas are associated with the Mancos shales. Both elevation and slope in these areas are the greatest of the Group 1 land types. Soils consist of sand with some dunes and outcrops of shales in the area. Vegetation consists of sparse grasses with mormon tea and snakeweed. Yucca and cacti are also present. All vegetation is very low with an average height of less than two feet.

Group 2 Land Types (RUGGED)

The rugged land types occur along the escarpments and edges of plateaus, mesas and buttes and in canyons. Elevation ranges from 6000 to 8000 feet. These land types extend over a great range of elevation resulting in a large variety of vegetation types. The common elements of these land types are the greater slopes and the increase in the amount of outcrop. These areas are not extensive and are generally found in narrow bands along the escarpment fringe in such areas as Black Mesa, the Defiance Plateau, the Luchachukai Mountains, and the Hopi Buttes.

Land Type Light Blue Tan Rugged

The image color of this land type is the same as the

Figure 23. Land Type Dark Tan (Sample subarea 39, along Coal Mine Canyon Escarpment north of Coal Mine Mesa)

Figure 24. Land Type Light Blue Rugged (Sample subarea 75, along Black Mesa Escarpment west of Rough Rock)

light blue tan area. The texture however displays very distinct ridges. This land type is found primarily along Comb Ridge, around the Second and Third Mesas, and along the Canyons of the San Juan River. It is upslope from the Light Blue Tan areas and is the lowest in elevation of the Group 2 areas. Sandstone outcrops, rock fragments, and sandy areas make up the surface. Clumps of grass, sagebrush, snakeweed, and rabbitbrush make up the vegetation, with shrubs being below three feet in height.

Land Type Light Blue Rugged

This image color displays light blue coloring with a texture of very prominent ridges. This land type is found along the Black Mesa Escarpment and the northern slopes of the Chuska Mountains (Figure 24). This area covers an elevation zone between the Light Blue Tan Rugged and the Brown Tan Rugged. Slopes in the sample areas averaged nearly 20 degrees and sandstone outcrops dominate the area. Pinyon, juniper and oak as well as sage and other shrubs are present, however the dominant vegetation in this land type consists of pinyon and juniper trees.

Land Type Brown Tan Rugged

This land type appeared as brown overlain with tan on a ridgelike texture on the Landsat images. This land type occurs at the higher elevations of the Group 2 land types. Found along the eastern and southern edges of the Defiance Plateau and along the Lukachukai Mountains, elevations range

from 6500 to 8000 feet and slopes average somewhat greater than 8 degrees (Figure 25). Outcrops of sandstone and siltstones prevail. The dominant vegetation in this area is ponderosa pine with aspen and Douglas fir in some of the higher areas. Oak, pinyon and juniper are present at lower elevations.

Land Type Hopi Blue

The Hopi Blue land type is a very distinct pattern of dark blue patches on the Landsat imagery surrounded by a field of Light Blue Tan. It is located in the Hopi Buttes section and associated with the Hopi Buttes volcanic field (Figure 26). The buttes and their surrounding slopes take on the dark blue image appearance. Elevations range between 6200 and 6500 feet and the underlying geologic formation is Bidahochi Volcanics. Angular basaltic fragments litter the surface in the samples of this area. Small sagebrush (less than three feet high) and mormon tea are the dominant shrubs, with juniper scattered very widely over the tops of the buttes.

Group 3 Land Types (JUNPIN)

These land types occur in the intermediate elevations of the study area and range from 5000 to 8000 feet. They extend over Black Mesa, the Defiance Plateau and in the lower elevations of the Chuska Mountains. The predominant vegetation consists of pinyon and juniper trees with some ponderosa pine in the upper reaches of this group. Sagebrush is the predominant shrub. The stands in this group are more dense and the plants are larger than the sagebrush found in groups 1 and 2.

Figure 25. Land Type Brown Tan Rugged (Sample subarea 74, along Lukachukai Mountains east of the Lukachukai Trading Post)

Figure 26. Land Type Hopi Blue (Sample subarea 41, on Tesihim Butte east of Coyote Spring)

Land Type Tan Brown

This land type displays a uniform tan brown appearance and occurs in the lower elevations of this group; usually between the Tan and Light Blue Tans of the basins and the Blue Greens of Group 3. Extensive areas are found along Moenkopi Wash, on First and Second Mesas and on the Defiance Plateau north of Canyon de Chelly. Soils are sandy and vary from light tan to reddish brown in color. Predominant vegetation in this area consists of scattered low sagebrush interspersed with widely scattered pinyon and juniper trees.

Land Type Blue Green

Generally higher in elevation than the Tan Brown is the Blue Green land type, the most extensive of the Group 3 land types. It is found along the lower elevations of the Defiance Plateau and on the lower elevations of Black Mesa (Figure 27). The elevation varies over the entire elevation range for Group 3, from 6000 to 8000 feet, and the mean elevation for the samples in this land type was 6850 feet. Sandstone is the bedrock in this area and soils are sandy, often with great expanses of bare sand among the vegetation. This land type typifies the pinyon-juniper zone and these two tree types along with sagebrush are the dominant plants. Sagebrush in the area is large, reaching a height of four or five feet and is usually associated with deep soil accumulations.

Figure 27. Land Type Blue Green (Sample subarea 18, in Moenkopi Wash)

Figure 28. Land Type Olive (Sample subarea 75, on Bodaway Mesa northwest of The Gap)

Land Type Blue Green Mottled

This land type is a subtype of Blue Green found only in the area south of the Colorado River in the southwest corner of the study area. The appearance on the Landsat images of these areas is a darker blue-green coloring with an uneven texture creating the mottled appearance. This area is associated with the San Francisco volcanic field to the southwest of the study area. The darker appearance is a result of the basaltic fragments which litter the surface. In some areas these fragments along with a few sparse clumps of grass cover the surface. Juniper and sagebrush, along with rabbitbrush, are found in other areas.

Land Type Olive

This is another subtype of the Blue Green which takes on an olive tone on the images. This land type is also located in the southwest portion of the study area along Bodaway Mesa, in small areas of the Painted Desert, and along the Little Colorado River (Figure 28). Outcrops, large boulders and angular rock fragments dominate the area. This land type is a direct result of the bedrock, the triassic Moenkopi formation of mudstone and siltstone, which gives this area its distinct olive color. Juniper and pinyon are the trees in the area, whereas the dominant shrubs are creosotebush, mormon tea and rabbitbrush of less than two feet in height.

Land Type Brown Mottled

This land type has a basic brown color on the Landsat image with an uneven texture. Occurring at slightly higher elevation than the Blue Green, it is found on level mesa tops of the Defiance Plateau, along slopes of the Plateau and in intermediate elevations on the slopes of the Chuska and Carrizo Mountains (Figure 29). Elevations in the mesa portions of the Defiance Plateau range between 6500 and 7000 feet while areas in the mountains range up to 7600 feet. Some of the mesa top areas are dominated by sagebrush with very widely scattered stands of pinyon and juniper. In the mountain areas this land type marks the upper limit of the pinyon, juniper and sagebrush dominated zone and is found at lower elevations than the Brown and Brown Blue Green land types.

Land Type Brown Blue Green

The image coloring of this land type is indicative of its place in the land type system, for it is made up of the overlap of brown and blue green and marks the transition between these two land types. It is found on Black Mesa at lower elevations than the Brown land type and on the Defiance Plateau at lower elevations than the Red Brown land type. Elevations range generally between 7000 and 7600 feet. Soils are light brown silts and sands. This land type is dominated by pinyon and juniper, with oak in some areas. Sagebrush, cliffrose, and buffaloberry were found within samples in these areas. Some ponderosa pine occur in the upper reaches of this

Figure 29. Land Type Brown Mottled (Sample subarea 12, on top of Ganado Mesa north of Ganado)

Figure 30. Land Type Red Brown (Sample subarea 81, in the Chuska Mountains south of Tsaile)

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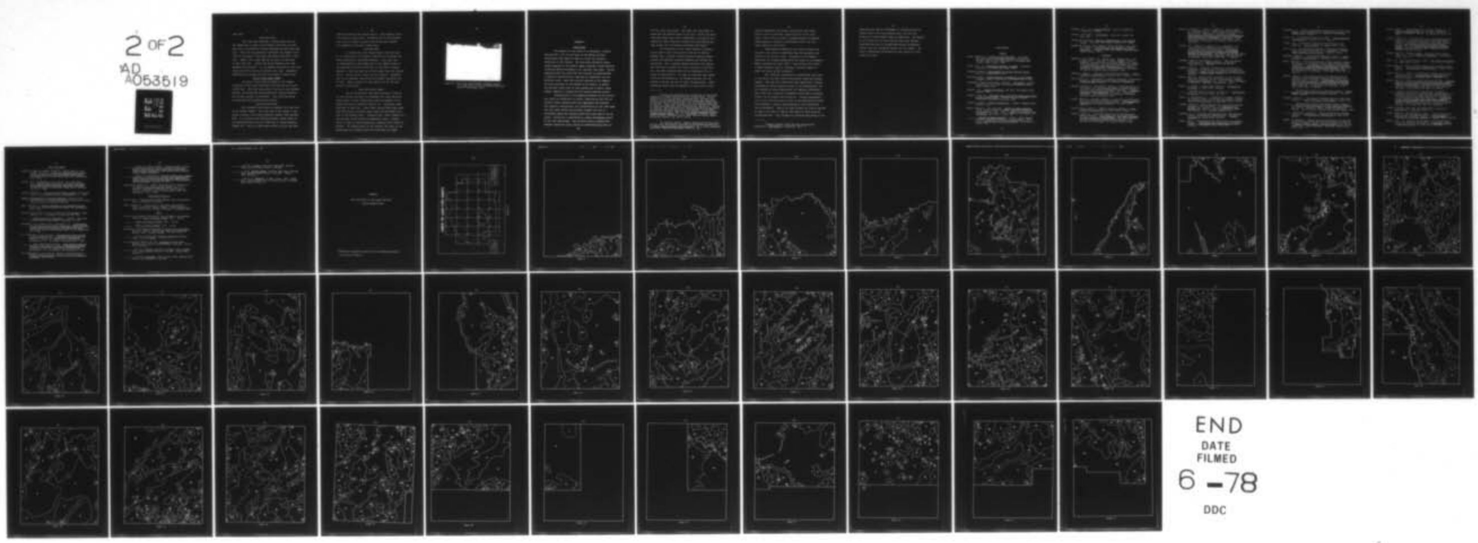

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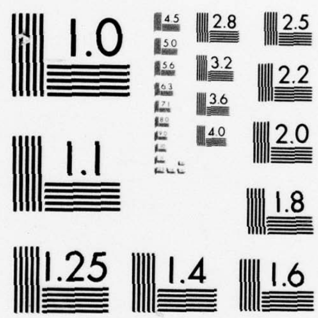

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land type.

Land Type Brown

This land type displays a uniform brown color on the images and is found in the highest elevations of Black Mesa and on the Defiance Plateau bordering the Red Brown land type. This land type generally represents the highest elevations of the group 3 land types and ranges from 6500 to 7700 feet. Sandy, silty loams make up the soils in some areas of this land type. Juniper and pinyon dominate with some ponderosa pine present. In the samples collected in this area, pinyon was by far the most prevalent tree type. Sagebrush, rabbitbrush and mormon tea are also present in these areas.

Group 4 Land Types (PINE)

The group 4 land types are found in the highest elevations of the study area above 7500 feet and up to over 10,000 feet. This land type group is located on the Defiance Plateau, the Chuska and Carrizo Mountains, Navajo Mountain, and in small pockets on Black Mesa. This land type group is associated with ponderosa pine forests.

Land Type Red Brown

Red intermixed with brown distinguish this land type on the Landsat images. This land type is the lowest in elevation of group 4 and occurs primarily between 7500 and 8000 feet. It is found on the Defiance Plateau, along slopes of the Chuska Mountains and up to 9000 feet on Navajo Mountain (Figure 30). Soils in these areas consist of silts and fine

sands and contain some organic matter. Pine needles litter the surface in many areas. Ponderosa pine is the dominant tree type but juniper, pinyon, and oak are also present with sagebrush occurring in many areas.

Land Type Red

A uniform red color characterizes this land type. It is found only in the higher elevations of the Chuska and Carrizo Mountains, and Navajo Mountain. This land type is found generally above 8000 feet to the highest areas of the mountains and over 10,000 feet on the crest of Navajo Mountain. Soils are made up of brown sandy loam with organic matter. Forest litter covers the soil surface. Ponderosa pine is the dominant vegetation with heights averaging over 65 feet. Aspen, Douglas fir and clusters of oak are also found in these areas.

Land Type Chuska Summit

One of the smallest land type coverages is made up of very distinct patterns of intermixed red, pink and green which appear in small depressions along the summits of the Chuska and Carrizo Mountains (Figure 31). Elevations range from 8500 to 9500 feet. These areas contain dark brown sandy loam with nearly continuous grass cover and wildflowers present in the meadows areas. Ponderosa pine, aspen, Douglas fir and oak grow in and around the depression areas. Ponding occurs in many of these depressions; numerous small lakes are present. If standing water is not present, the soils in the depressions are saturated with water and many are boggy.

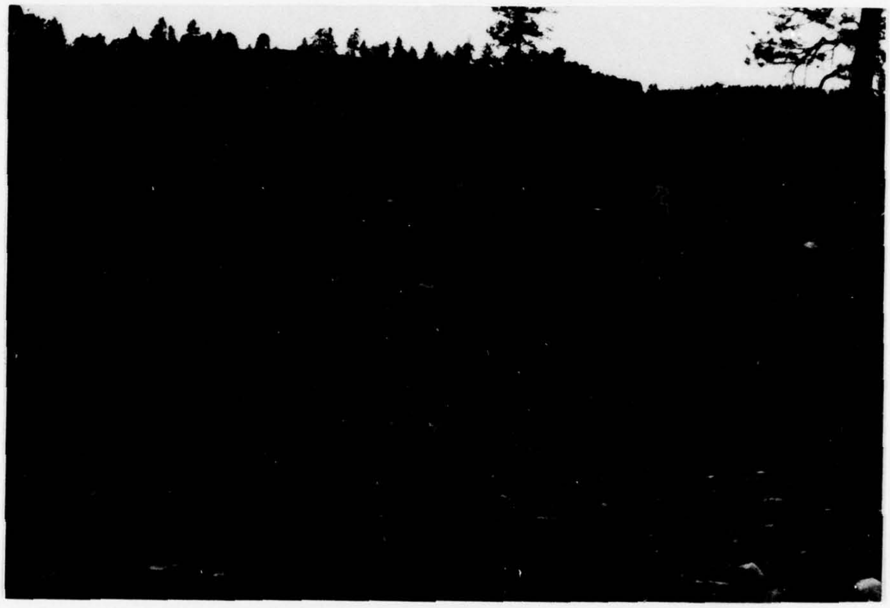

Figure 31. Land Type Chuska Summit (Sample subarea 63, along the crest of the Chuska Mountains north of Washington Pass)

CHAPTER V

CONCLUSIONS

The purpose of this study is to delineate, classify and describe a set of land types on the Navajo and Hopi Reservations that might be used as a basis for resource evaluation of the terrain. The land areas defined by photomorphic mapping of the Landsat images represent actual physical conditions which correspond to the specific land types. Ground sampling within the study area has provided an understanding of physical characteristics that may be responsible for the different color, tonal and textural patterns on the imagery. The main advantage of this method is the ability to define and describe large areas of land rapidly and in detail using Landsat imagery in conjunction with ground sampling results.

Although much of the mapping procedure and the derived land types are subjective in nature, quantitative data for individual sample subareas have been aggregated and analyzed. This analysis substantiates the classification of the land types into four major groups and provides insight into the relationships among the variables which have been used in the analyses. Elevation is identified as a major determining factor of the land type groups. The elevation factor coupled with dominant vegetative types results in differentiating three of

the four land type groups. The other land type group is based upon the general slope of the area. Within the major land type groups more subtle differences in elevation and vegetation types along with surface soils and bedrock geology account for the nineteen different land types.[1]

An alternative to the visual method of interpretation used in this study would be the use of digital Landsat data. However, digital analysis requires sophisticated and expensive computer hardware and software for processing. Also, programs dealing directly with digital data encounter problems with scene variations, cloud shadow, and other problems which can be compensated for in visual interpretation.[2] In light of costs and time limitations for interpretation, the optimum procedure for the current study was the use of visual interpretation. Other techniques which could be applied to a study such as this

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[1] Poulton has discussed the interaction of soils and vegetation on image characteristics in arid areas. He has pointed out that in sparsely vegetated areas the bare soil surface is the dominant feature controlling image characteristics especially in small-scale, low resolution imagery such as Landsat. Soils were pointed out as the dominant indicator of land types Dark Tan, Blue Green Mottled, and Olive. Charles E. Poulton, "The Feasibility of Inventorying Native Vegetation and Related Resources From Space Photography," in National Aeronautics and Space Administration Earth Resources Aircraft Program Status Review, Vol. II, Agriculture, Forestry, and Sensor Studies, September 16-18, 1968 (Houston Texas: Manned Spacecraft Center), pp. 40-14, 40-15.

[2] H. Dennison Parker, "Remote Sensing For Western Coal and Oil Shale Development Planning and Environmental Analysis," in Remote Sensing Energy-Related Studies, ed. T. Nejat Vexiroglu (New York: John Wiley and Sons, 1975), p. 186.

include enhancement procedures using filters and single bands to pick out specific characteristics of the landscape. This could be useful in seeking further and greater understanding of thematic relationships within the land types defined in this study.

Technological advances in the field of remote sensing will also assist in improving upon the procedures and results of the current study. Successors to the Landsat satellites are already planned with the launch of the Thematic Mapper scheduled for early 1981.[3] This system will include a larger spectral range of coverage, a greater number of bands and better ground resolution.

This study was successful in establishing land types on the Navajo and Hopi Indian Reservations based upon Landsat imagery. The land types which have been identified, although providing an overall general picture of the Reservations, are not intended as final explanations for regional differences. These land types establish a framework within which subsequent studies can be planned and carried out. Through experimentation or more detailed study of land on the Reservations within this framework a greater understanding of land differences can be determined. Results of these studies can then be applied to land of the same or similar land types in other areas of the Reservations. Only through the continued monitoring of the

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[3] "Thematic Mapper: More Uses For Earth-Survey Satellites," <u>News Report</u> 27 (February 1977): 2.

land resources and the refinement of classification procedures such as the one presented here, can the full potential of these Indian lands be understood. The benefit to the tribes who live here derived from land resource investigations must be accomplished without detrimental effects upon the ecological balance of this region. The base of information established in this study is a step toward that goal.

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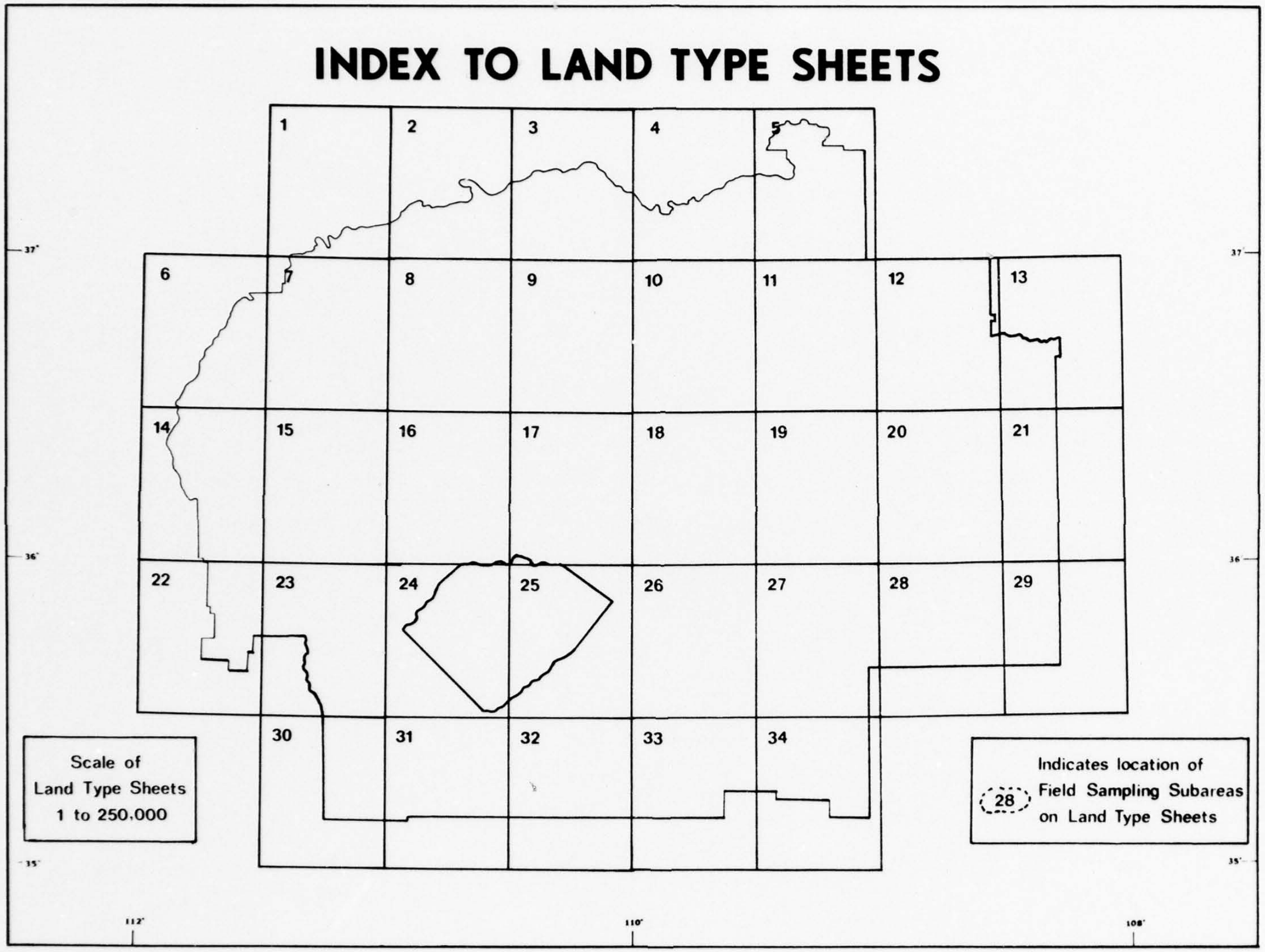
APPENDIX

LAND TYPE MAPS OF THE NAVAJO AND HOPI INDIAN RESERVATIONS*

*Numerical designators used on the following map sheets are listed in Table 2.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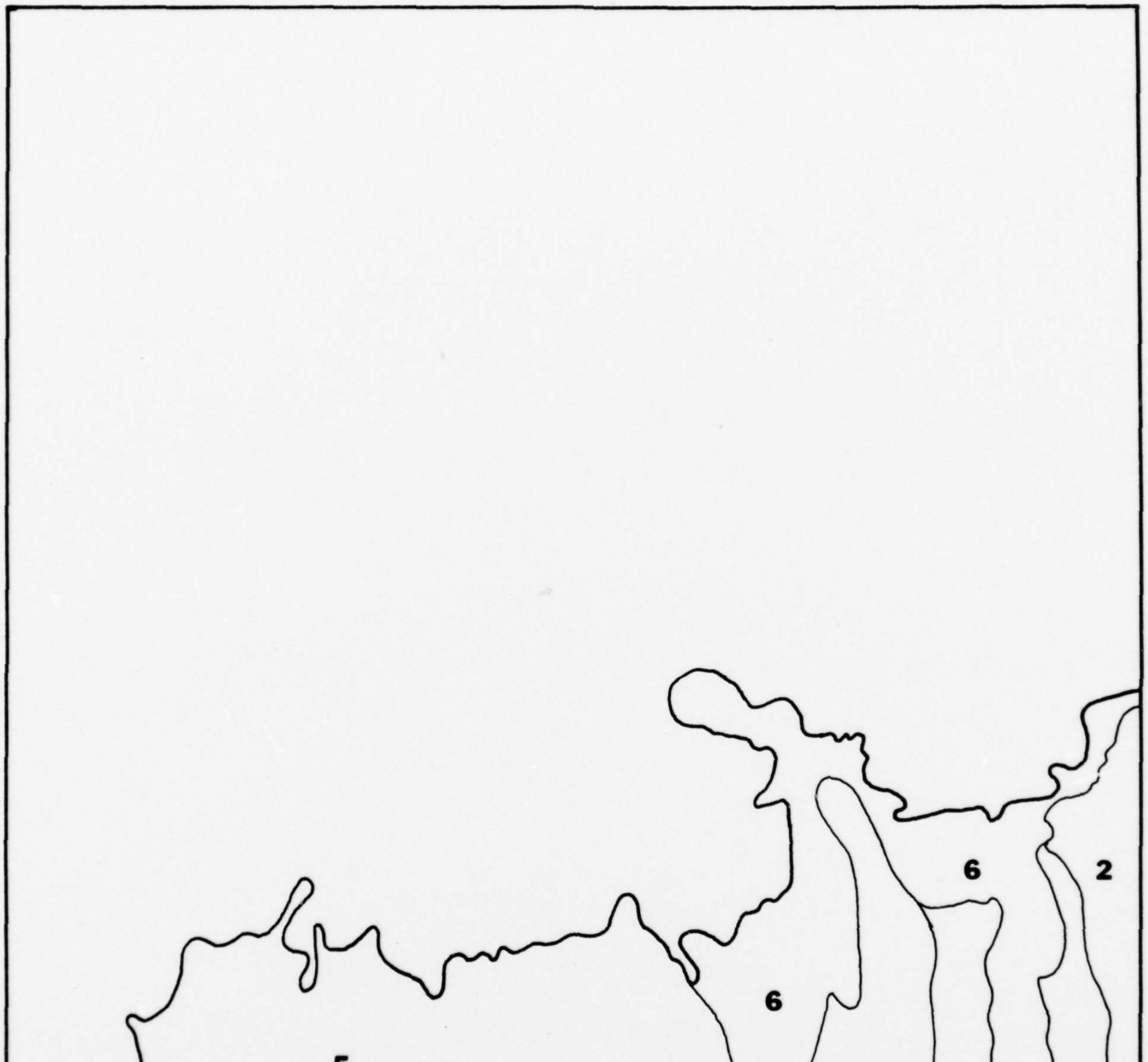

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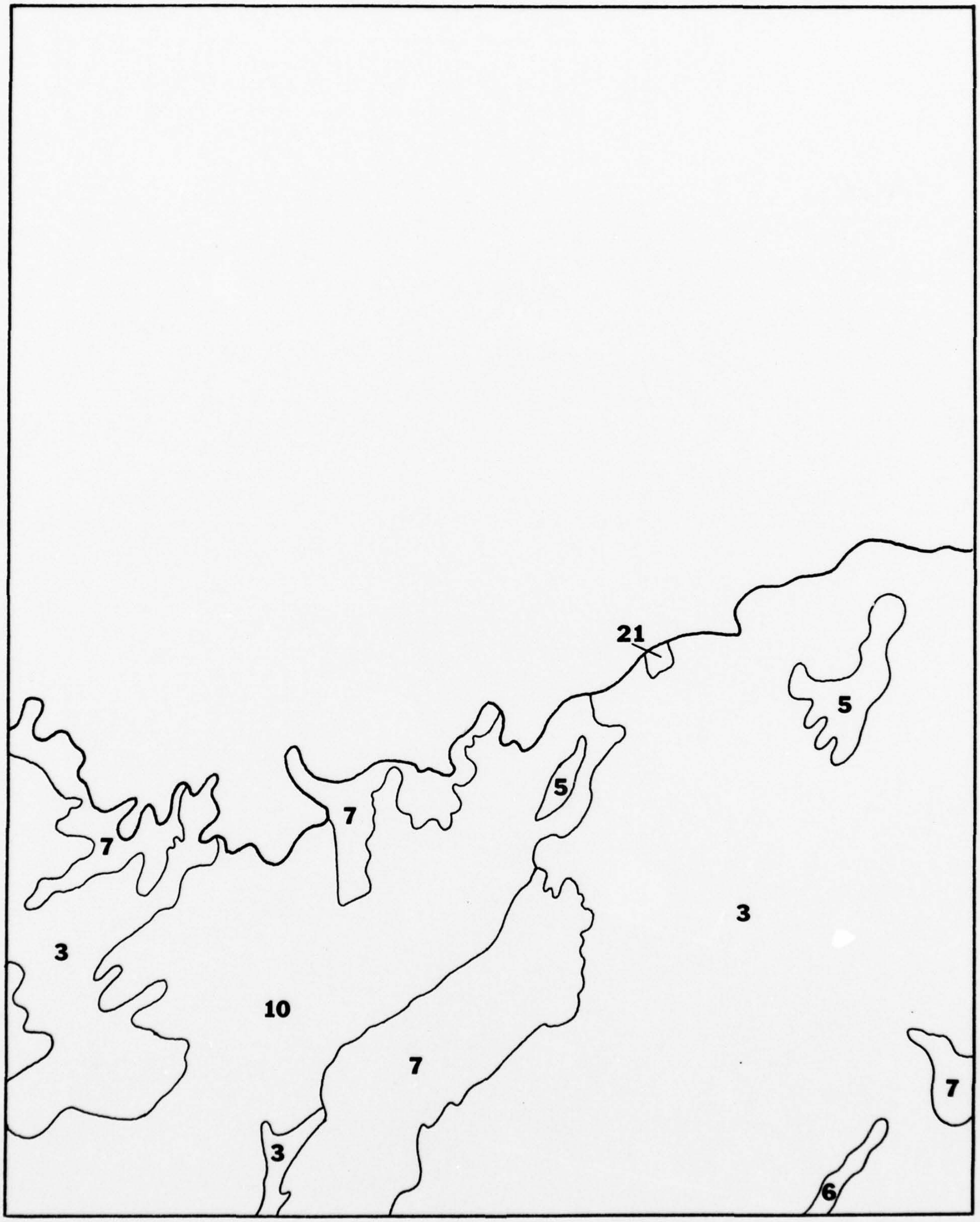

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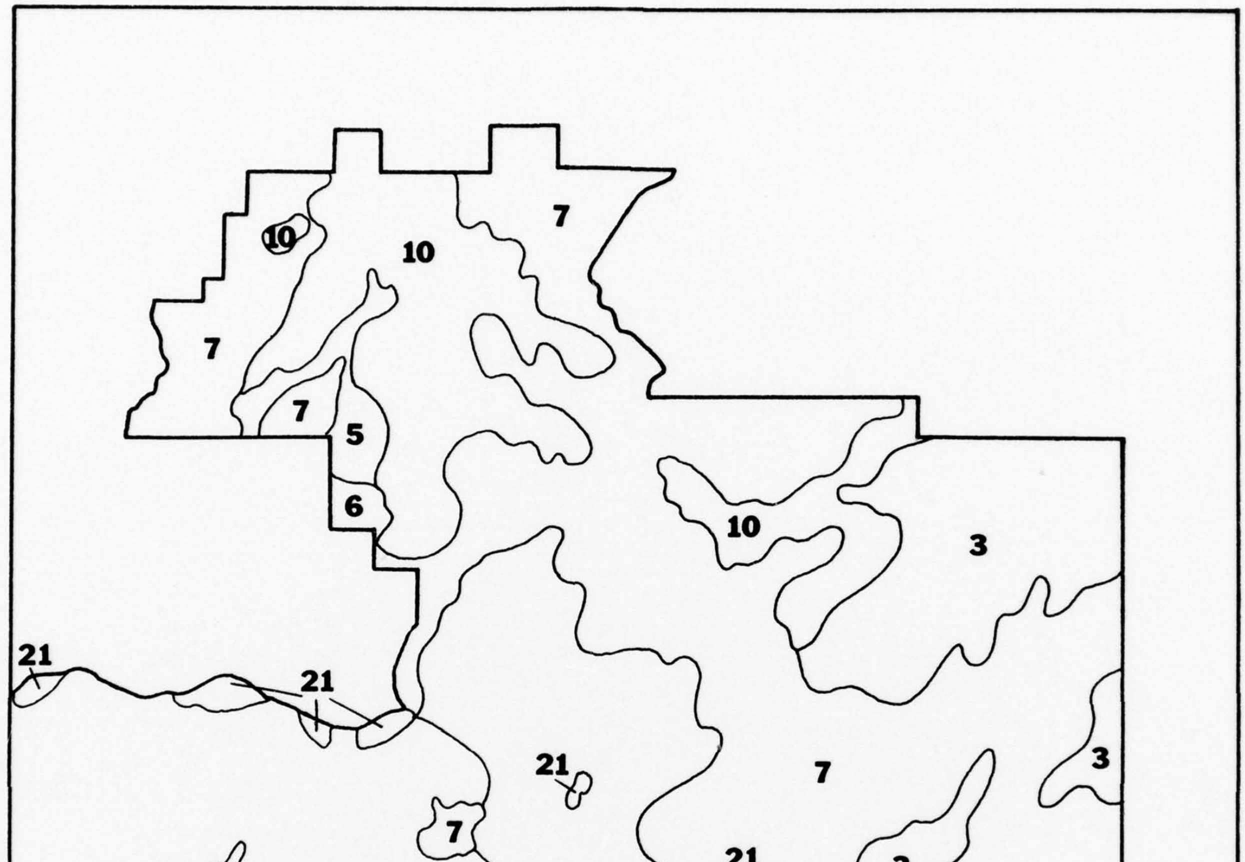
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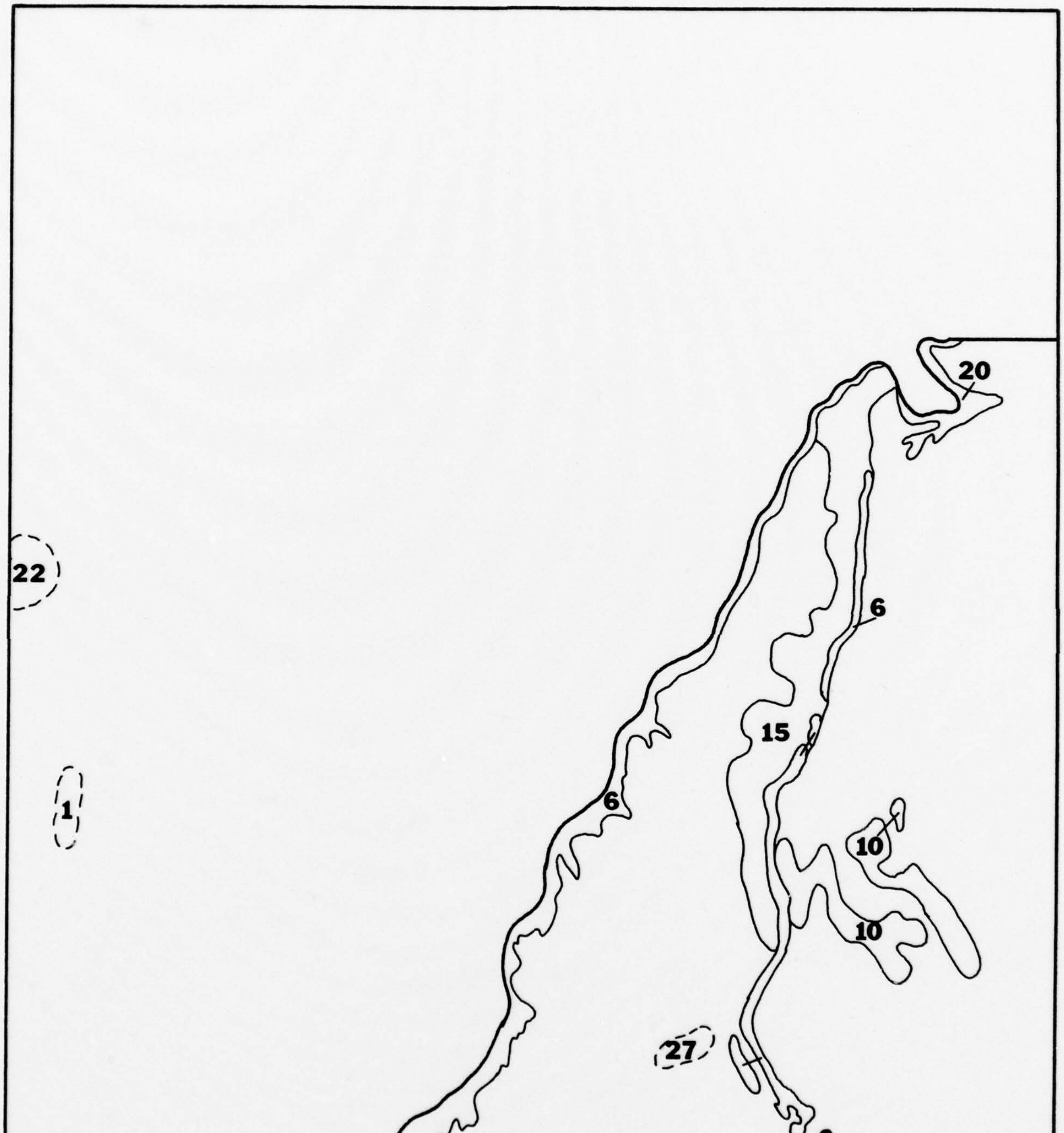

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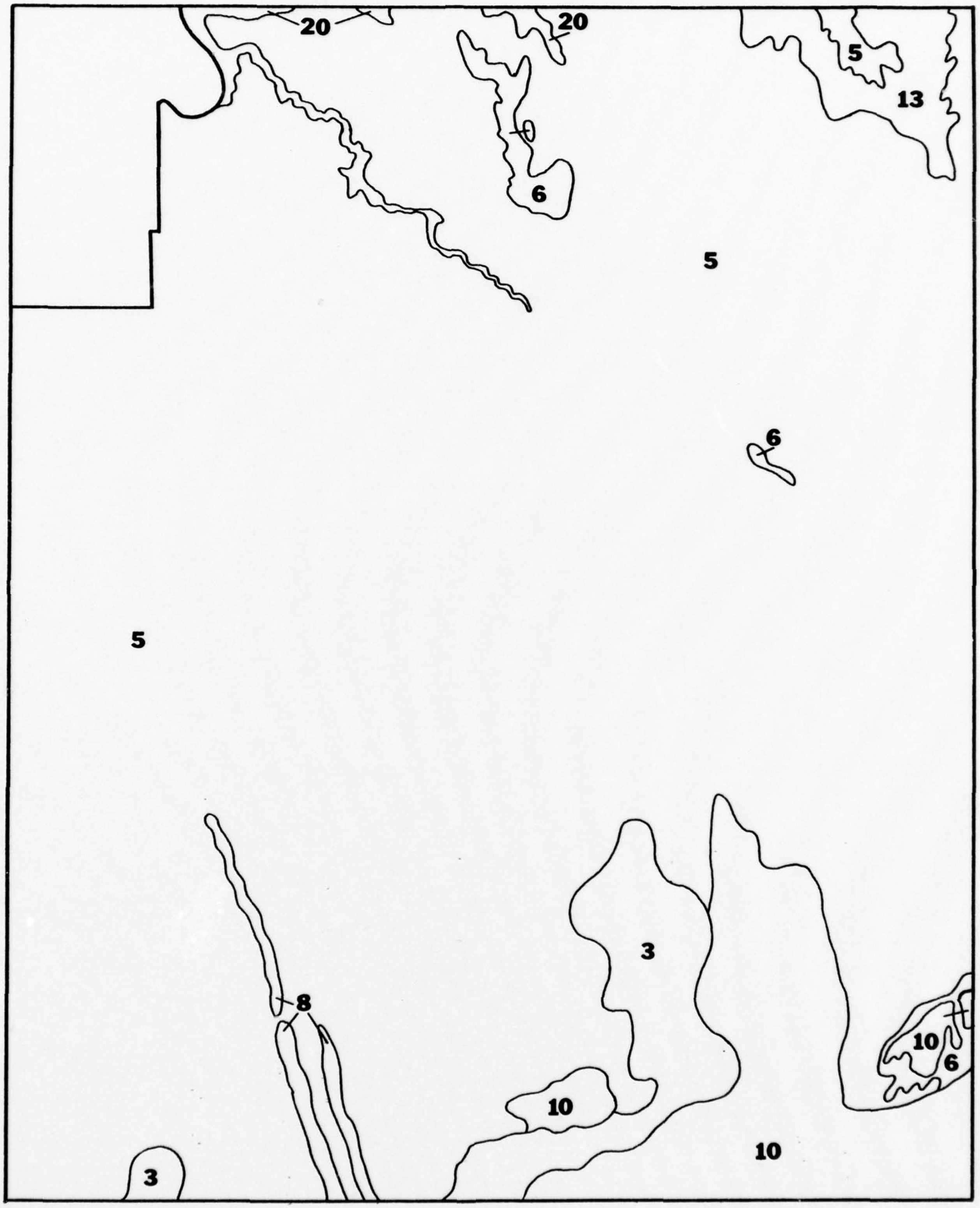

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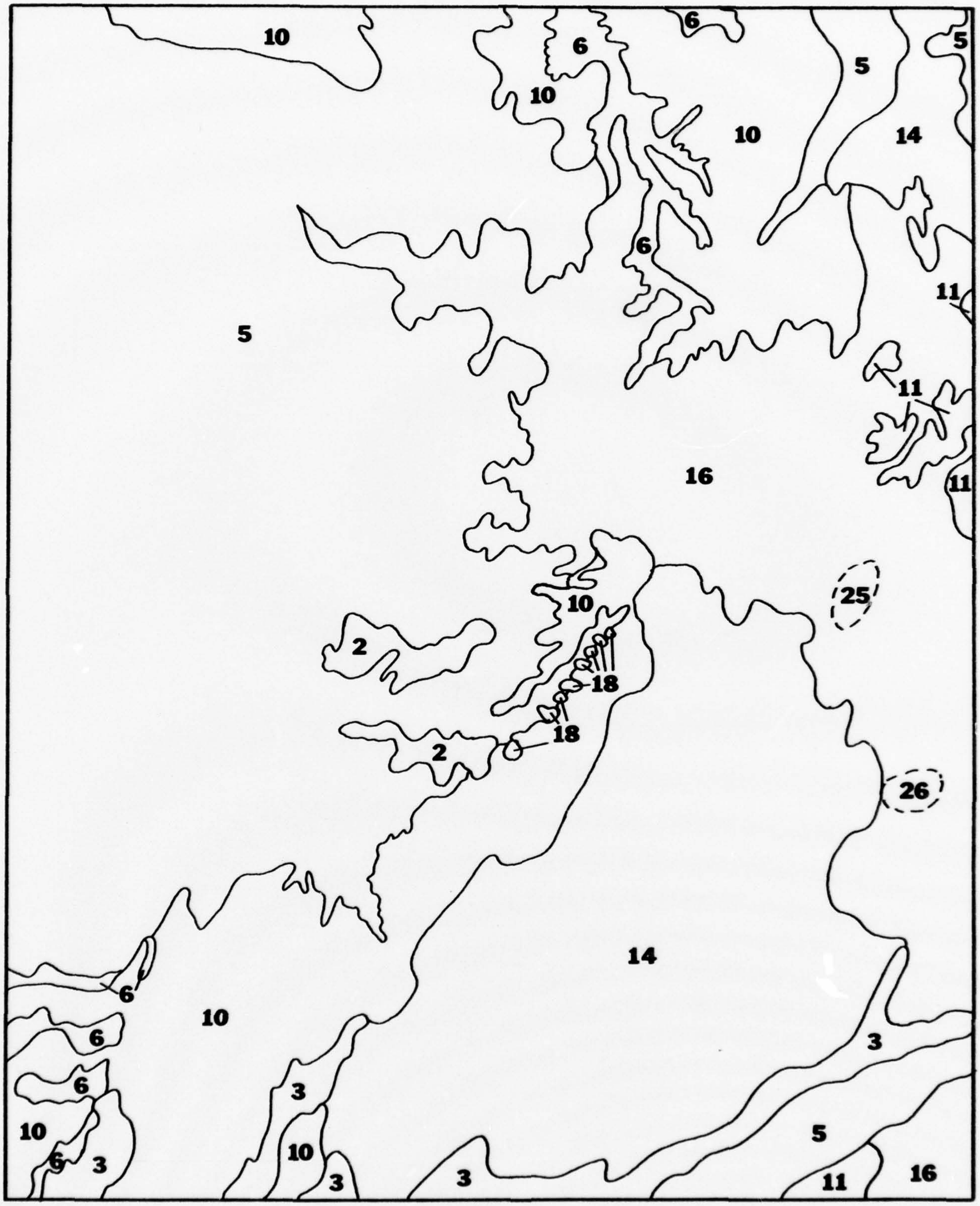
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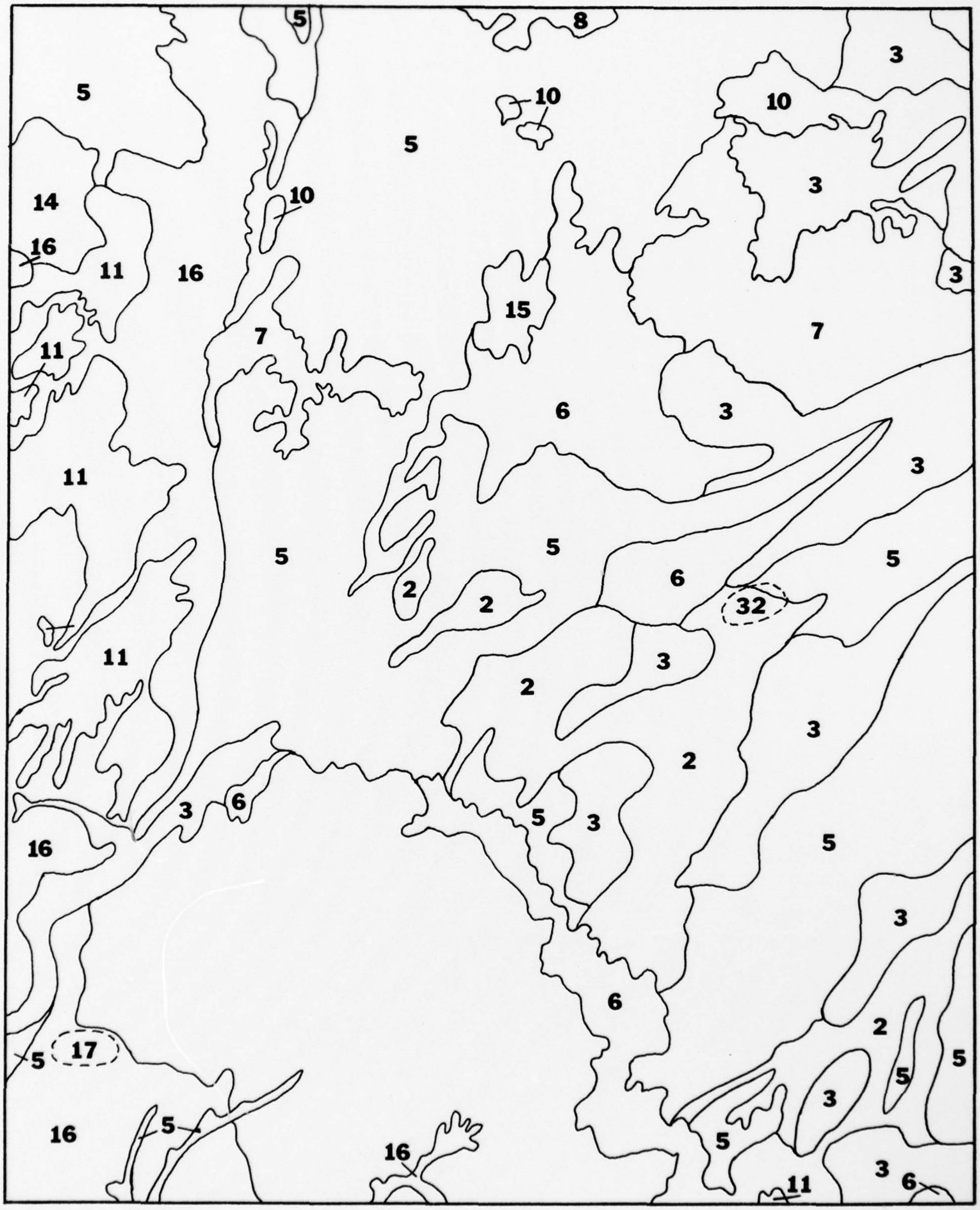
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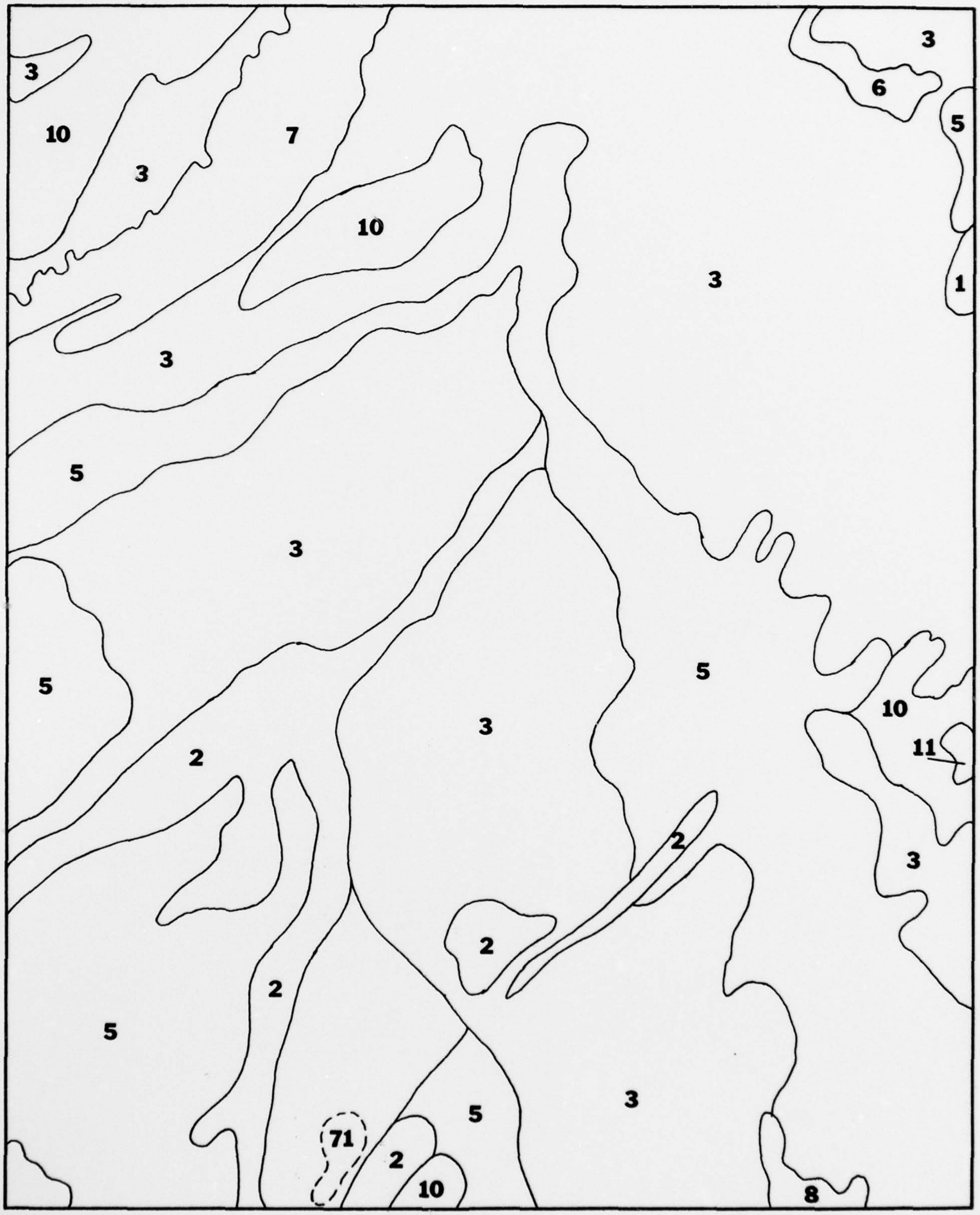

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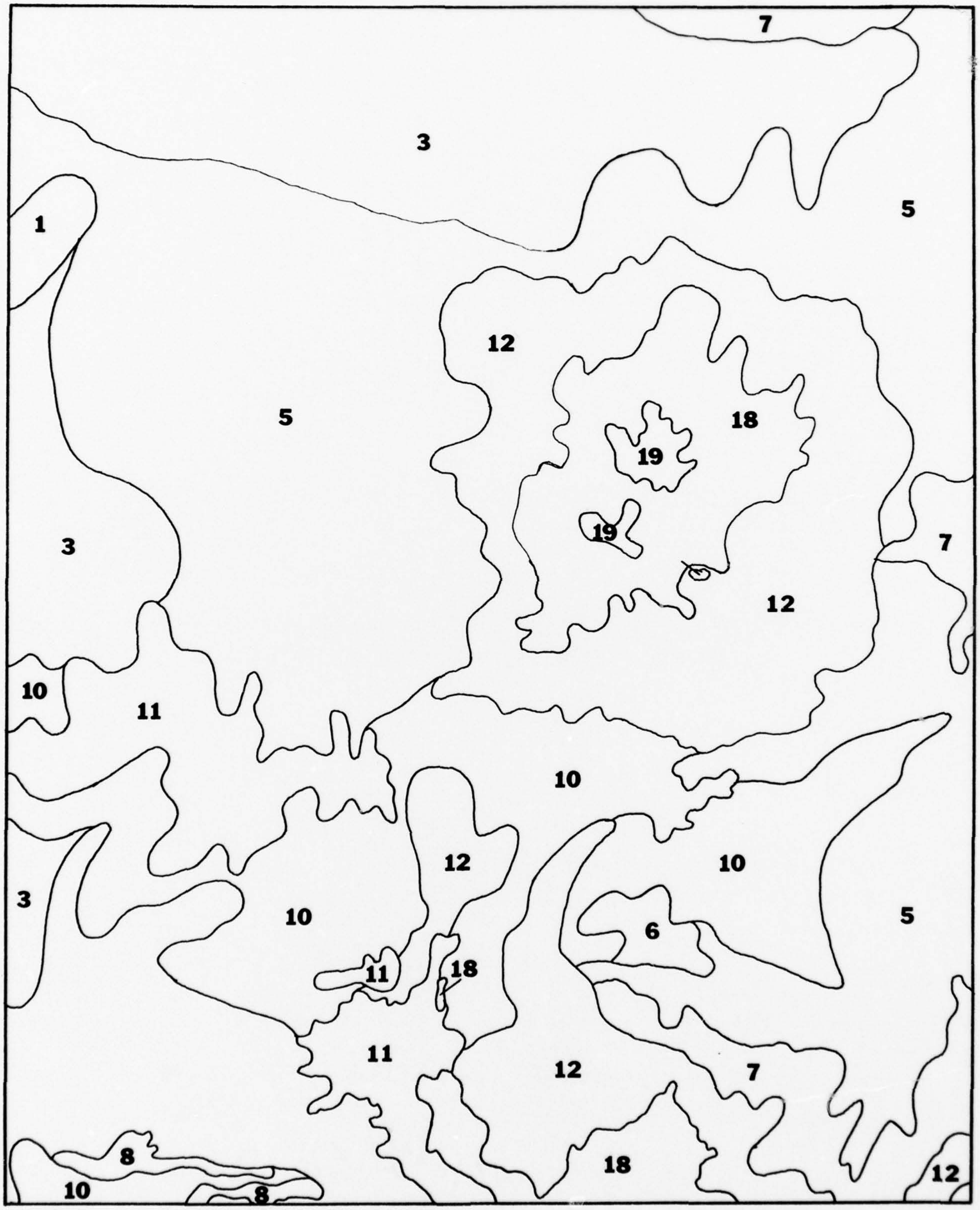

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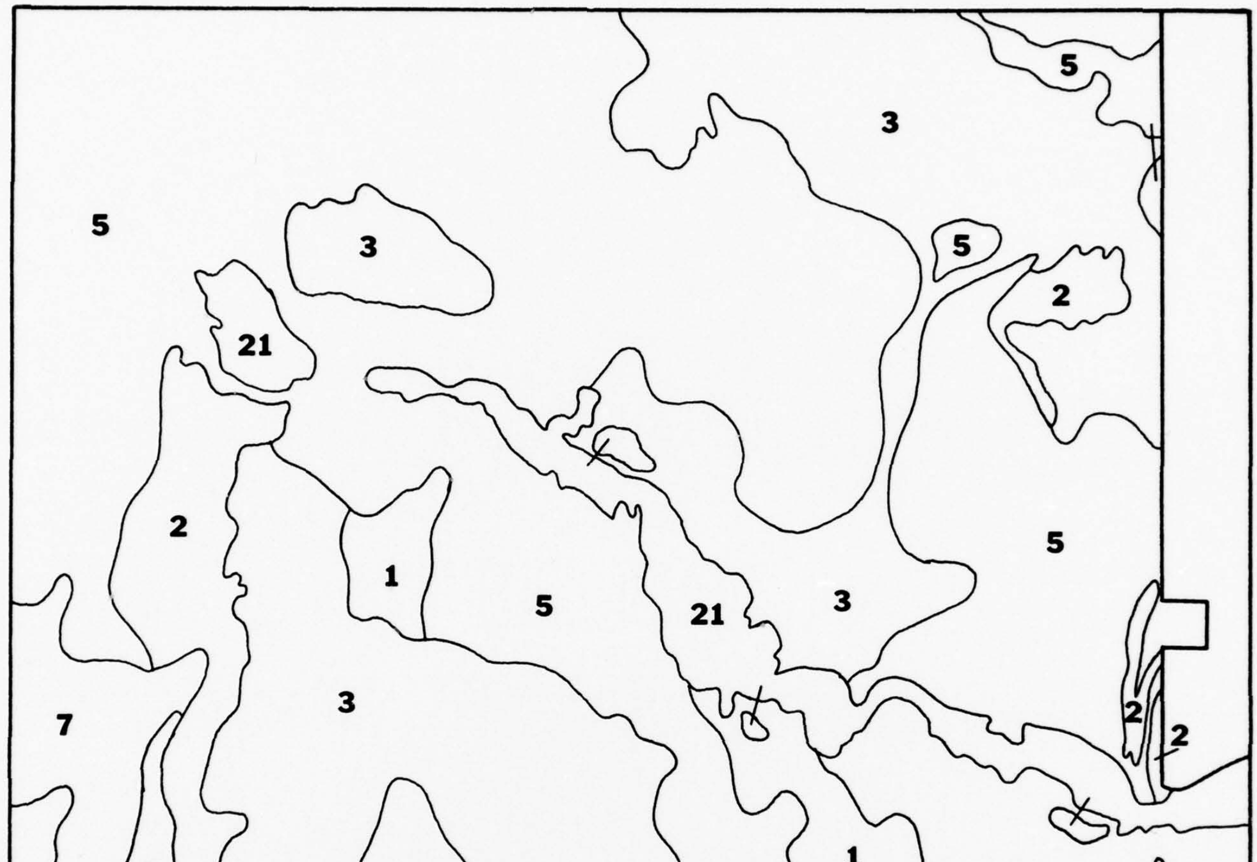

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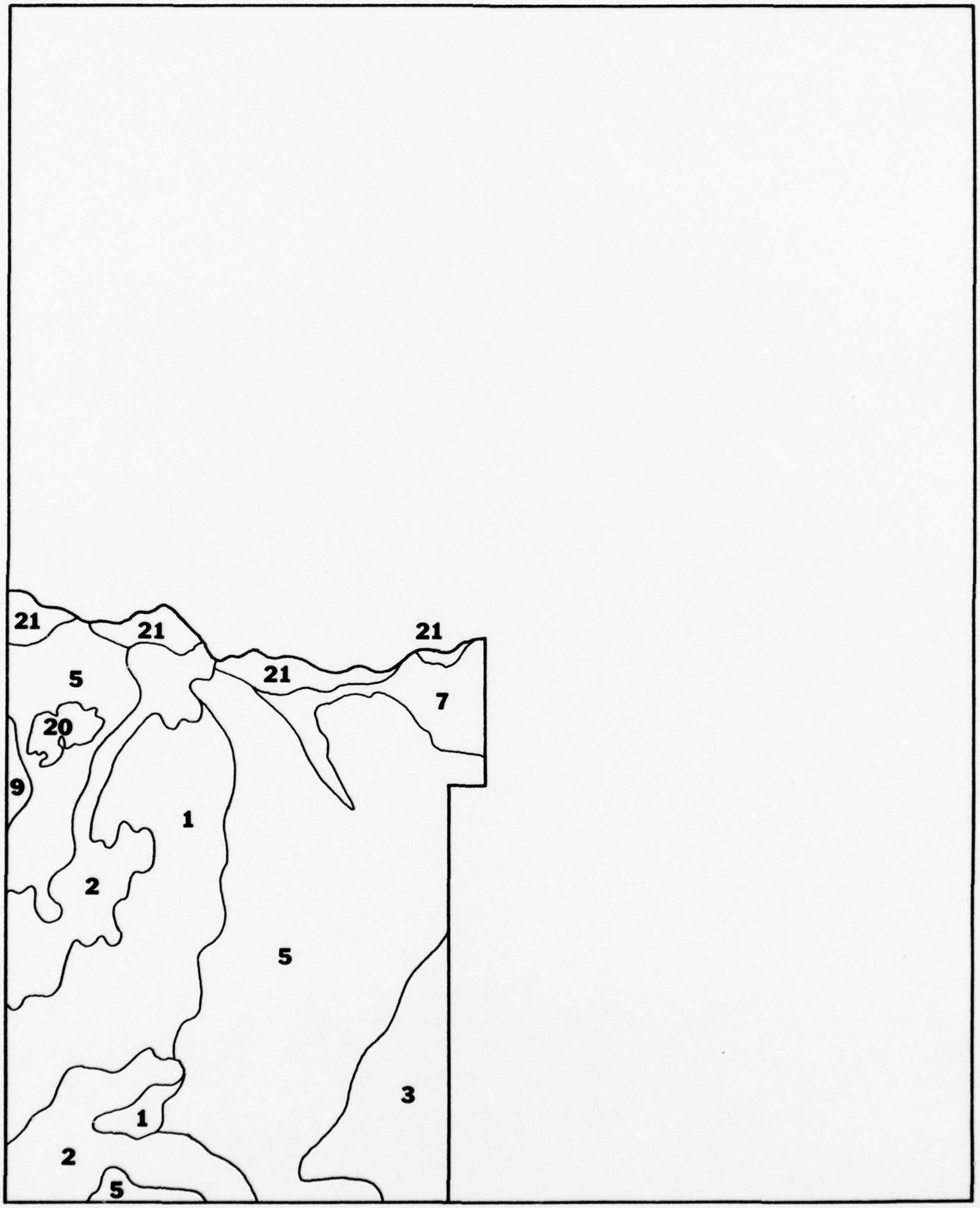

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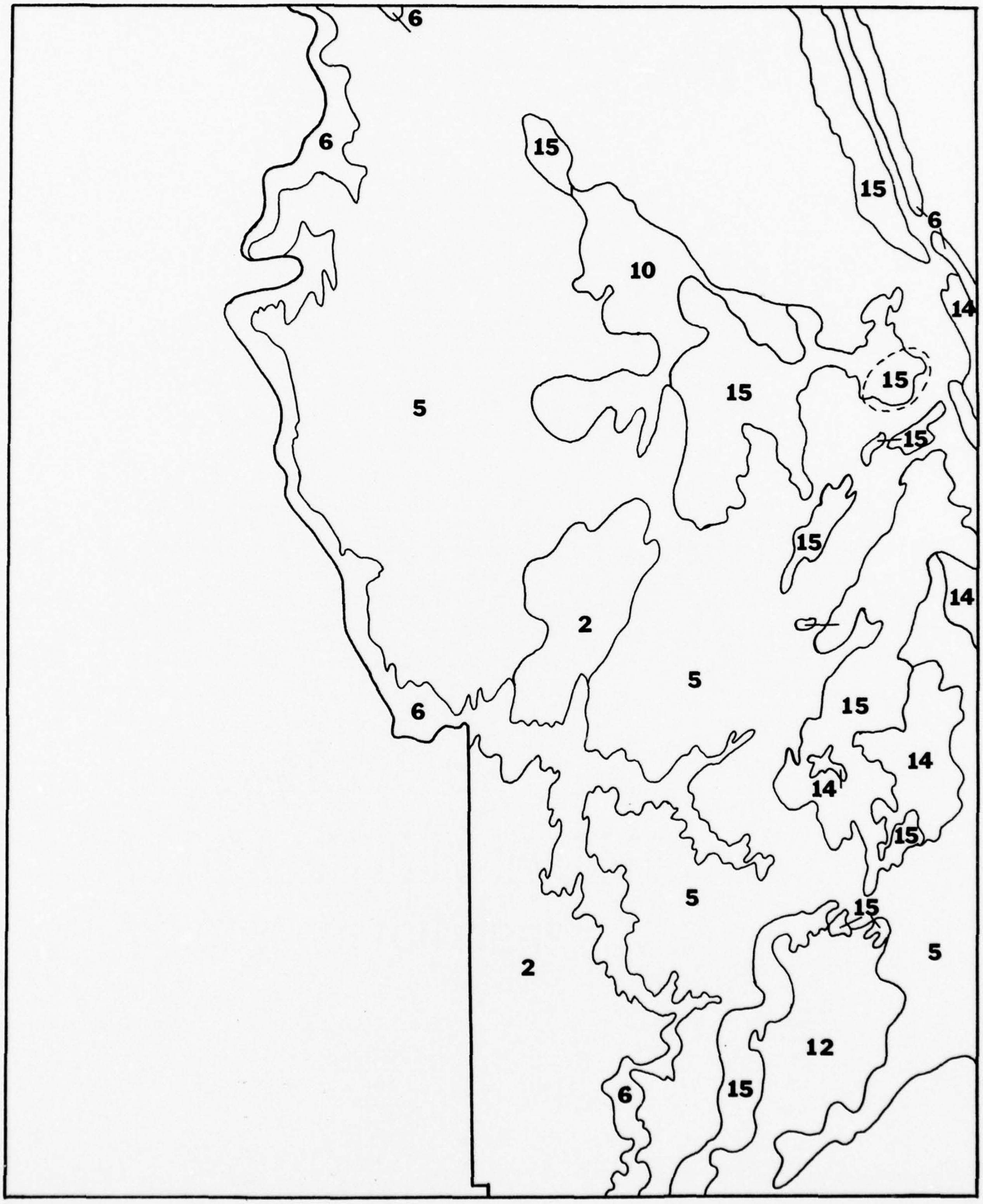

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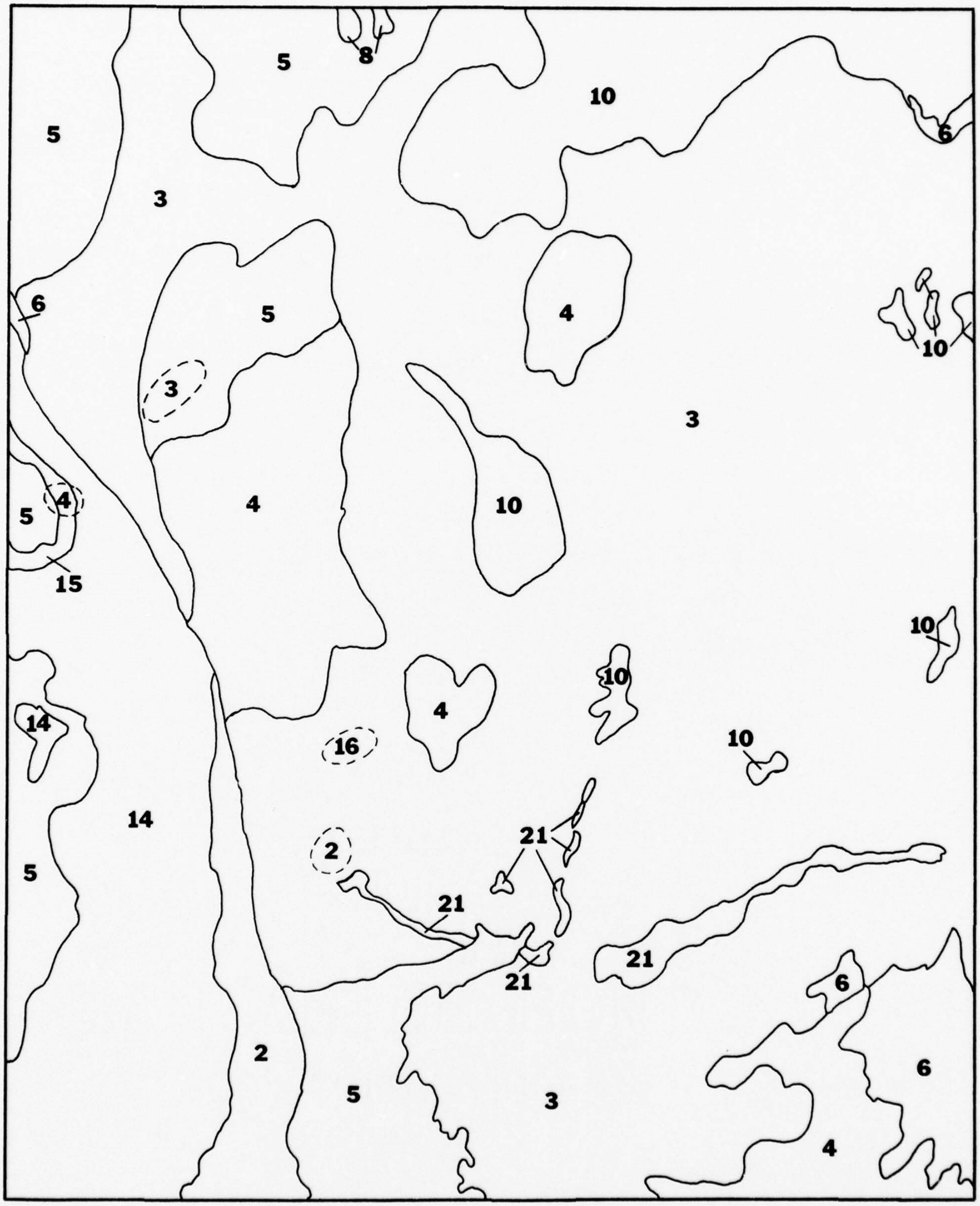
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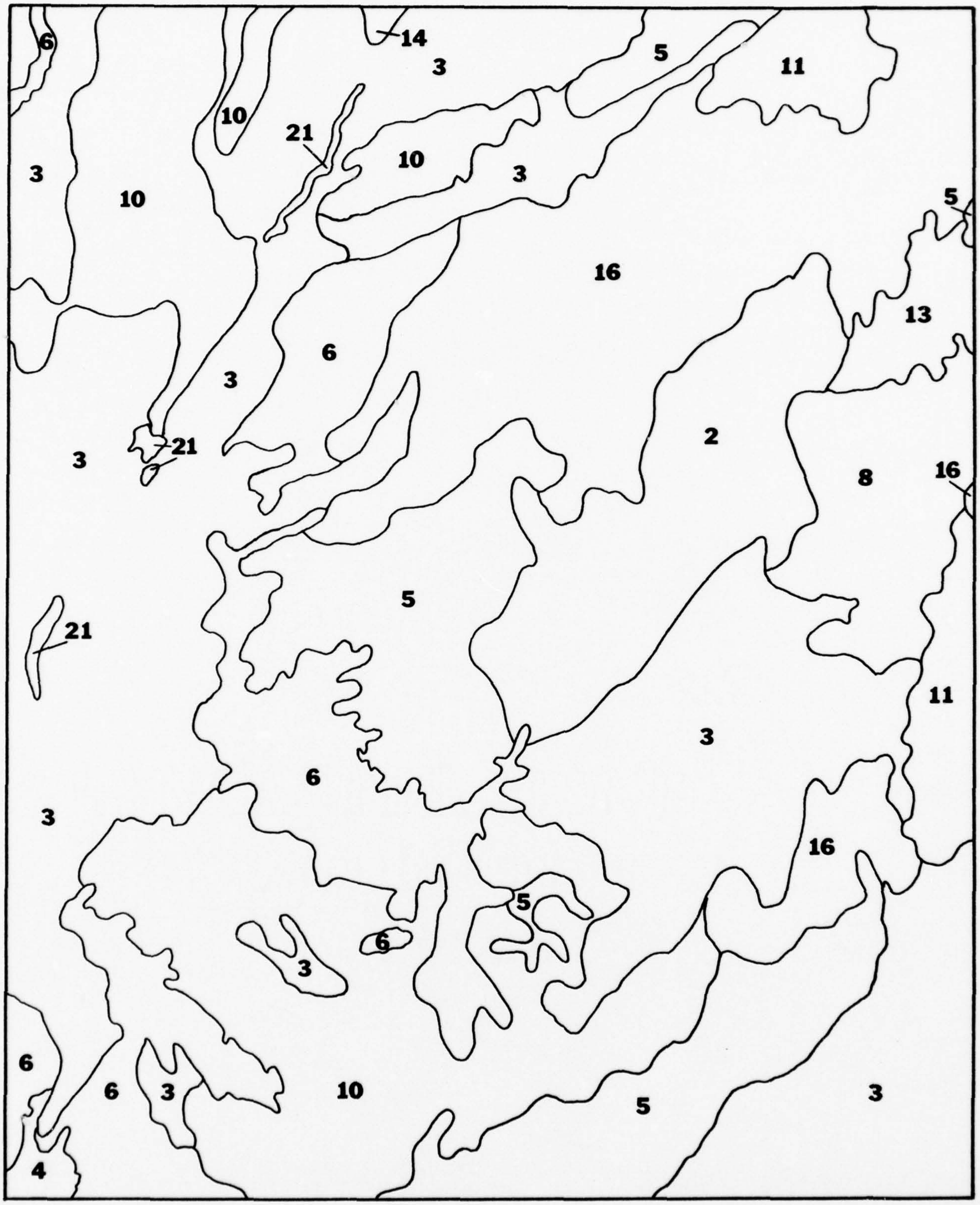
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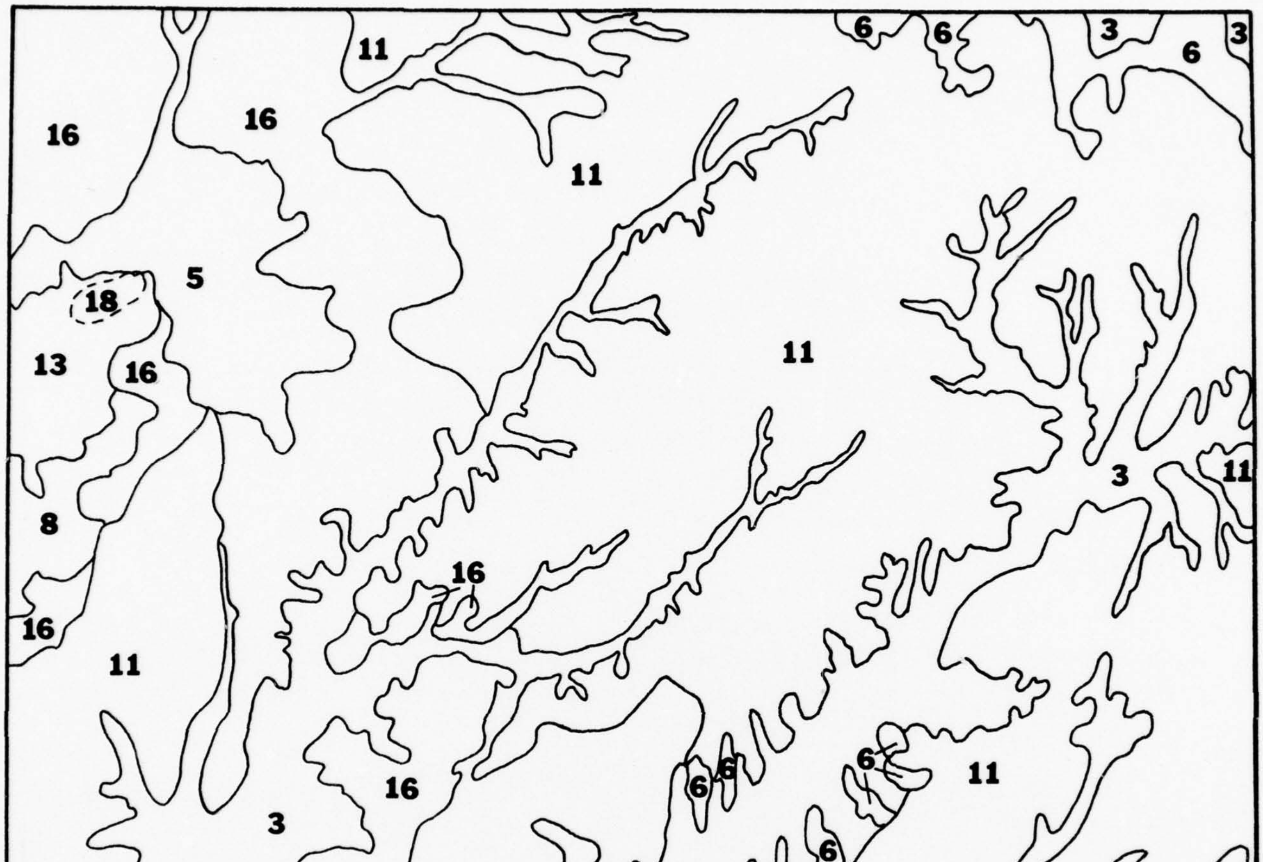
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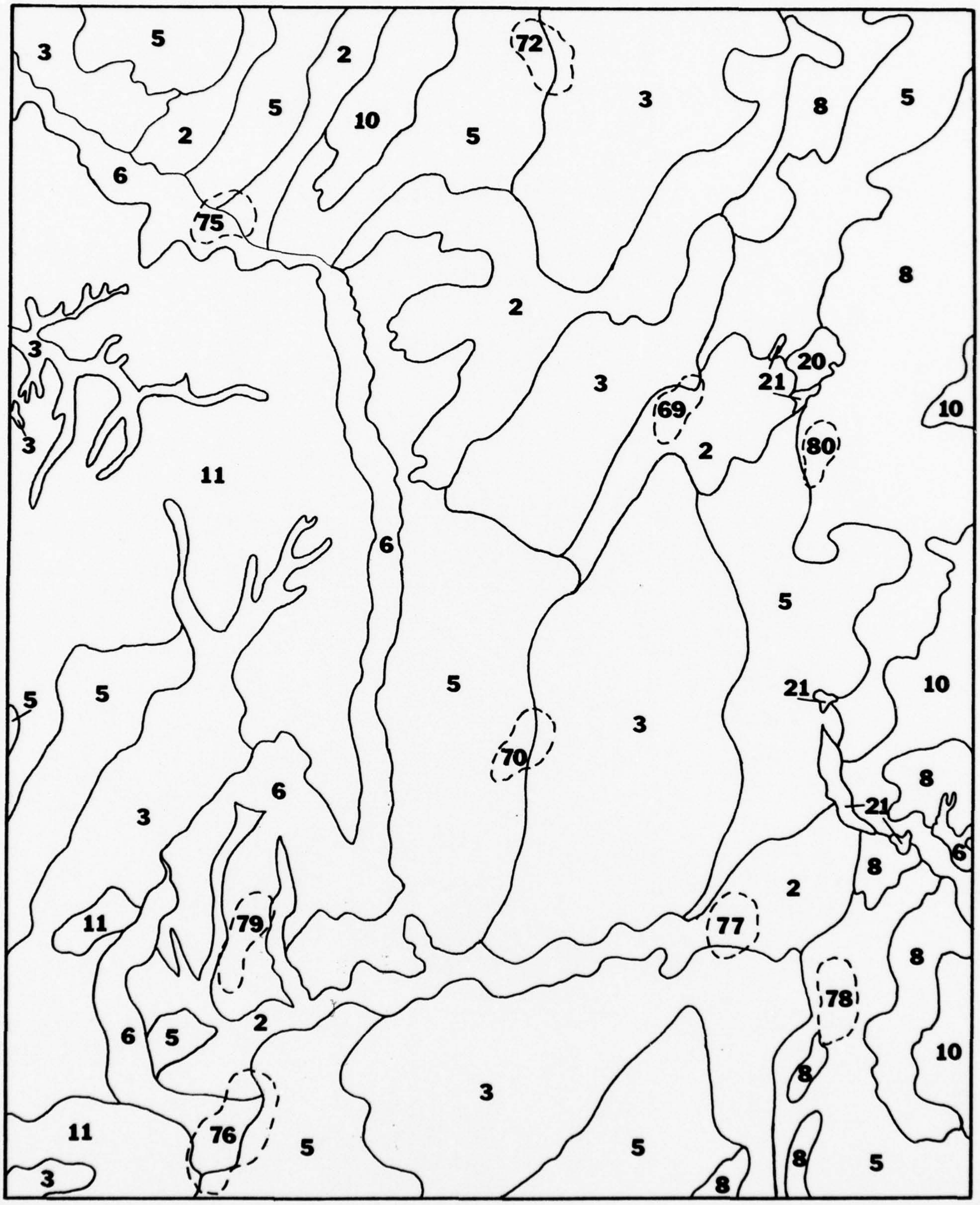
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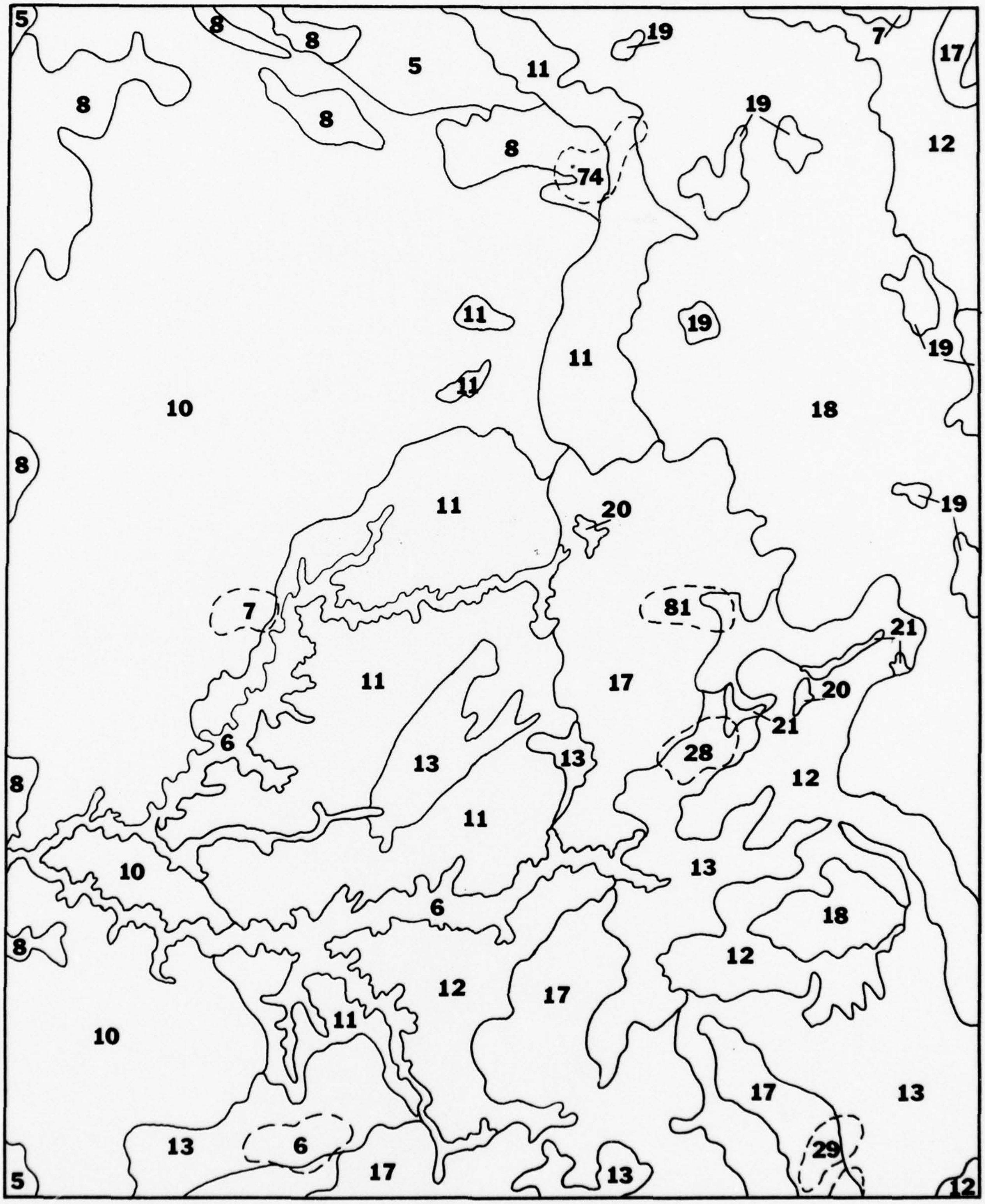
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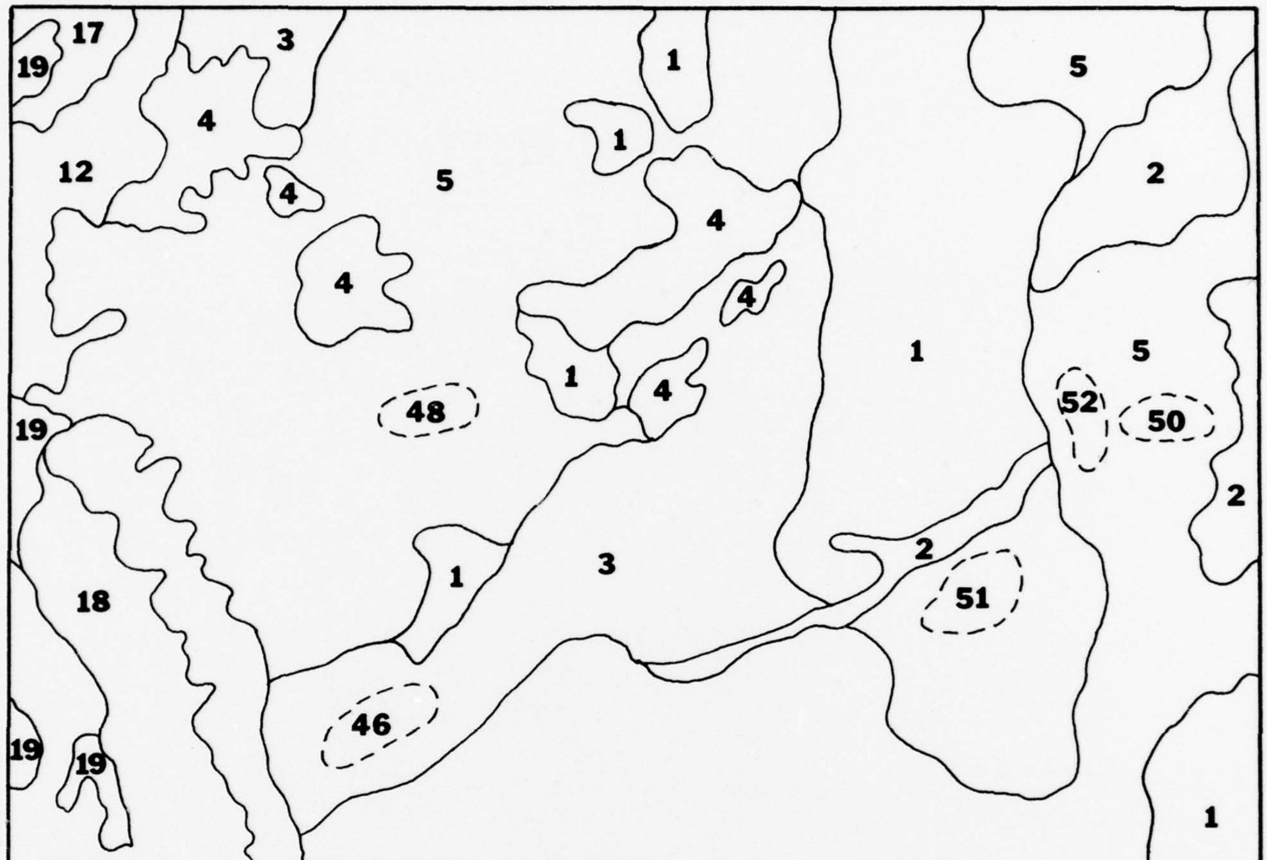
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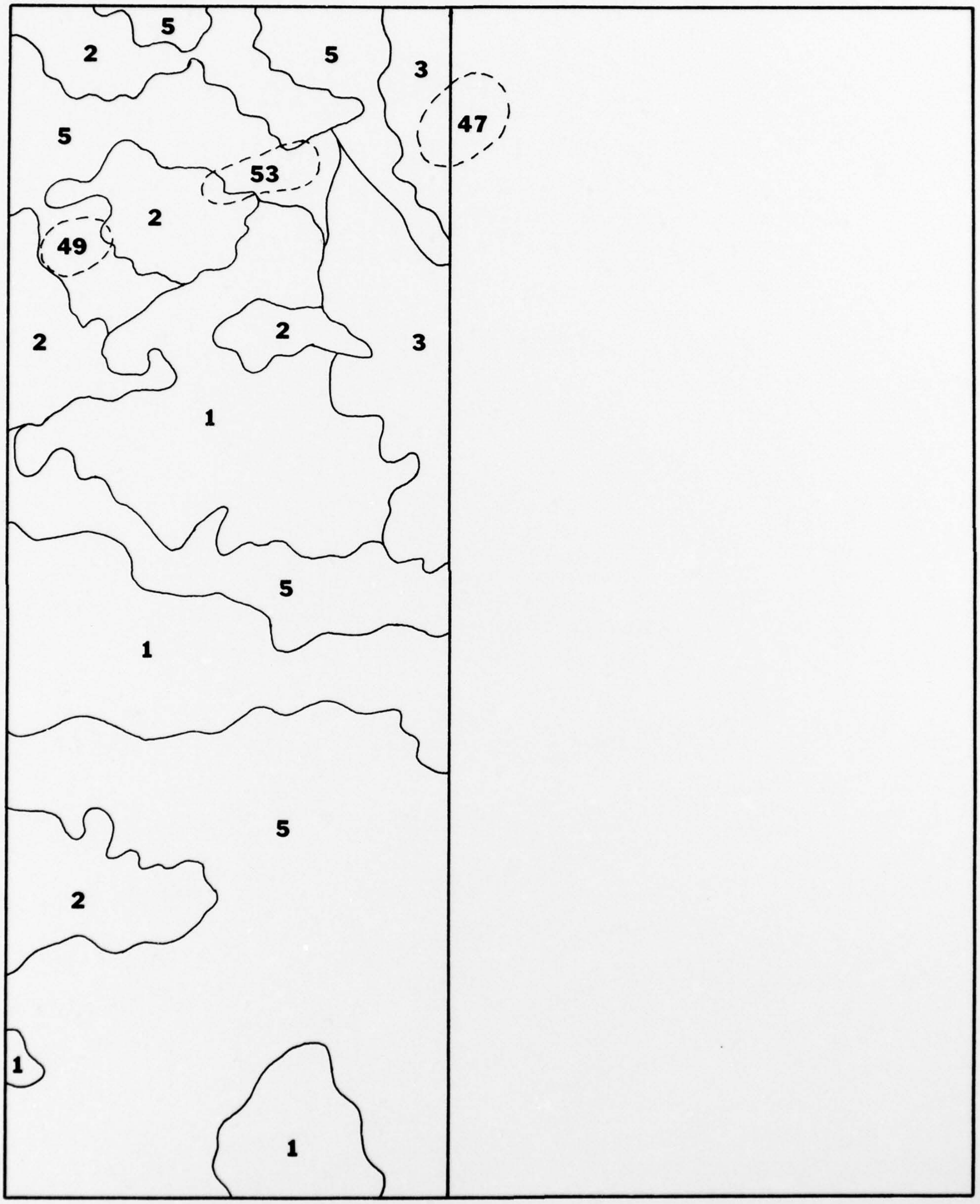

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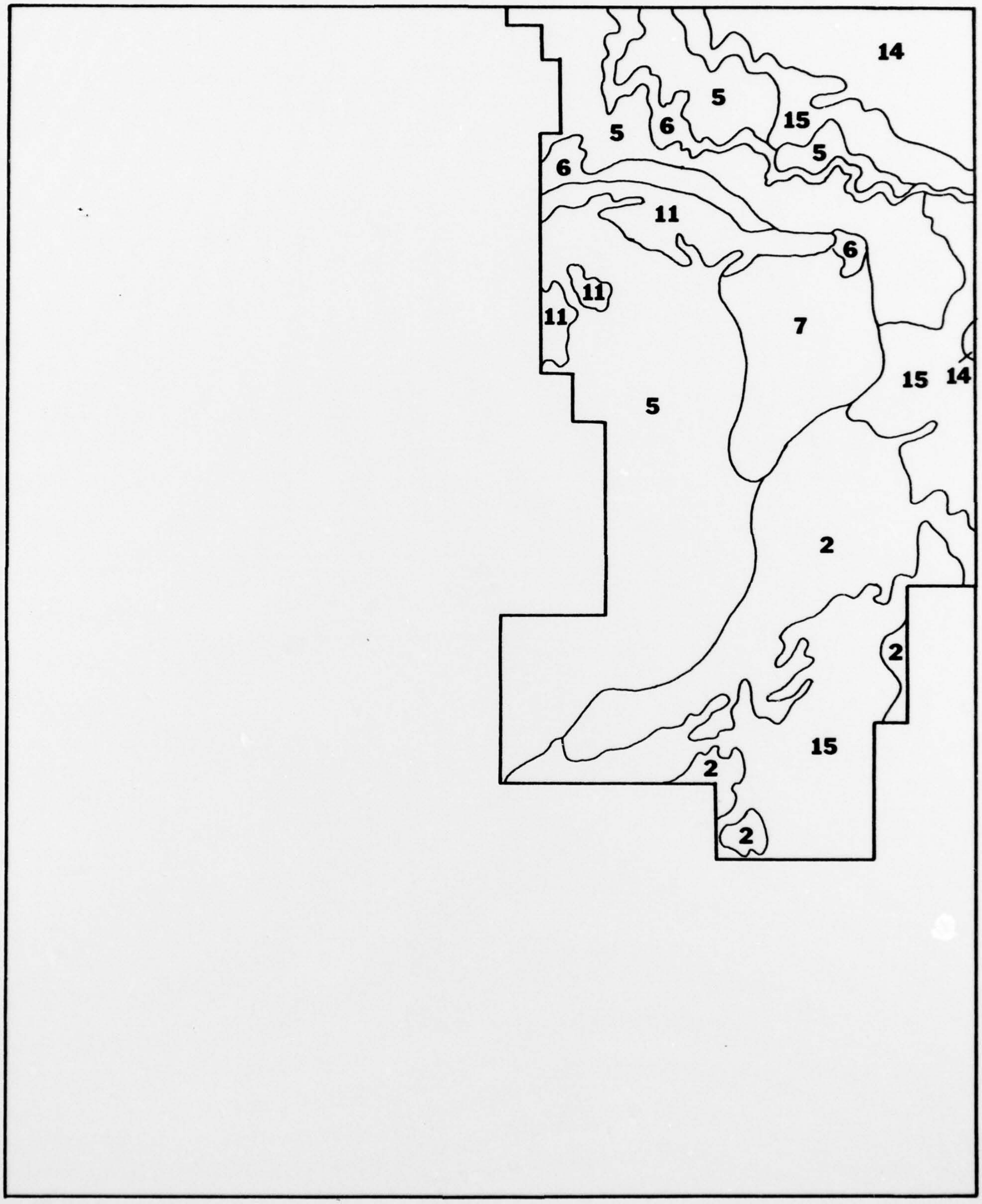

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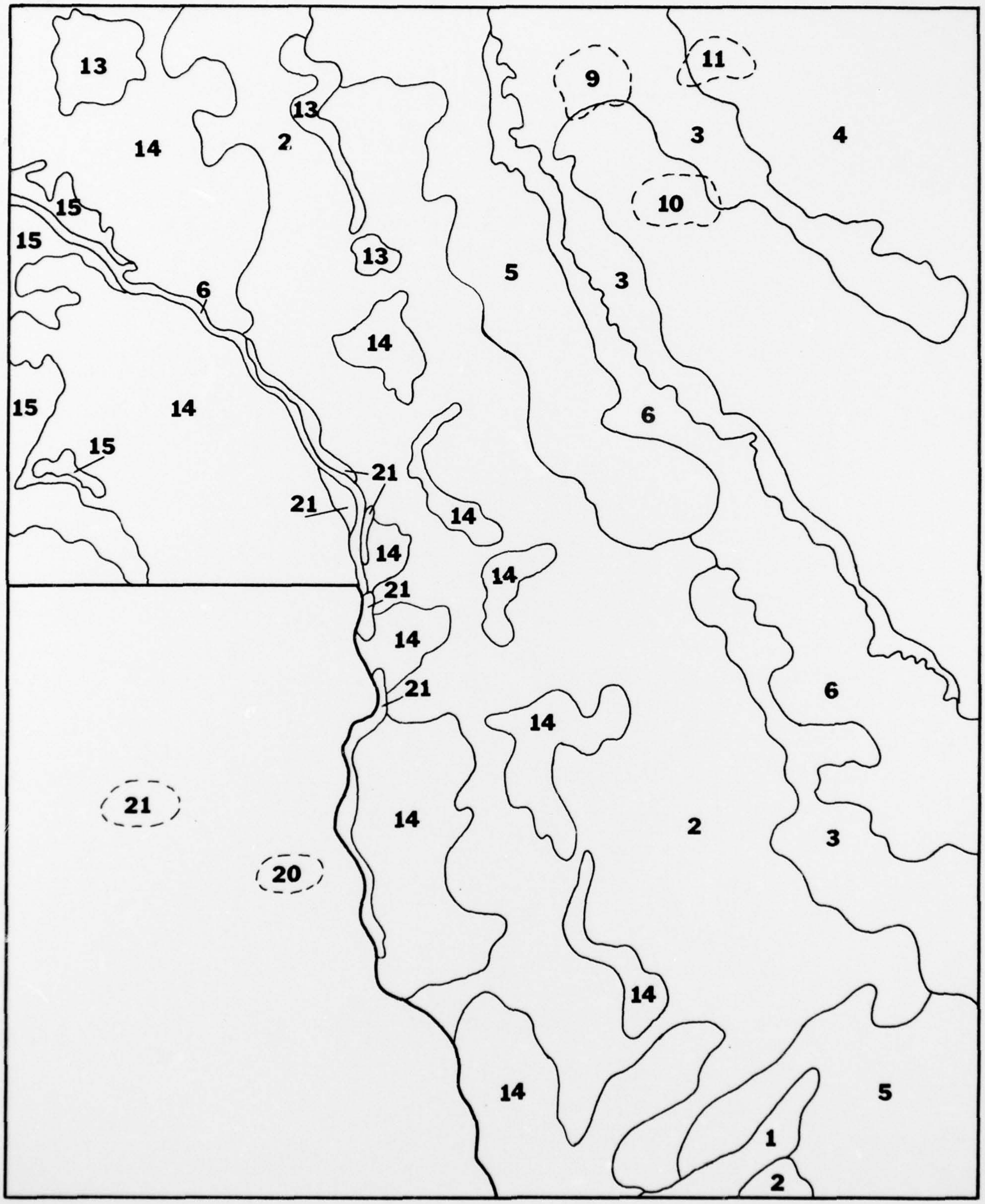
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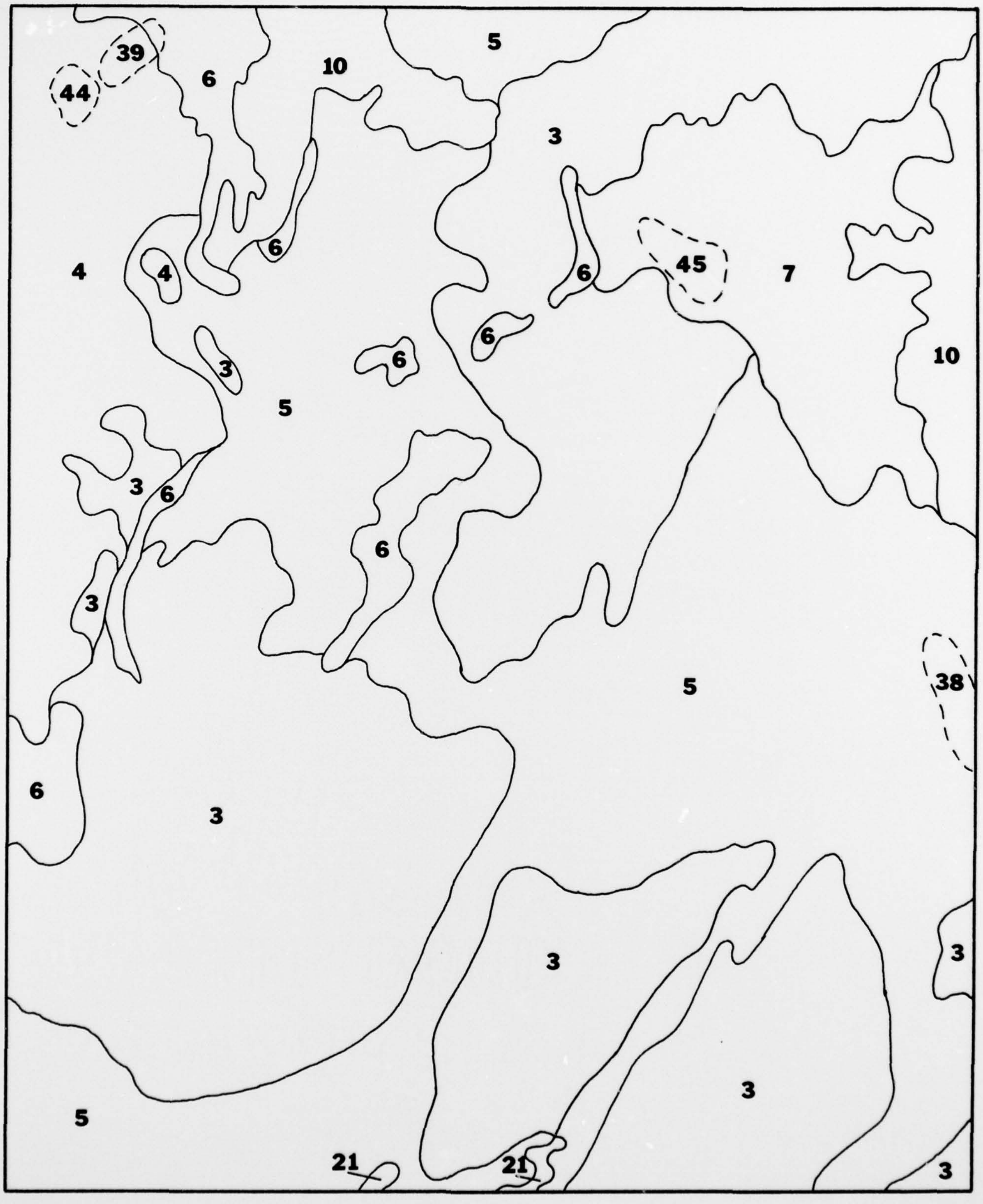

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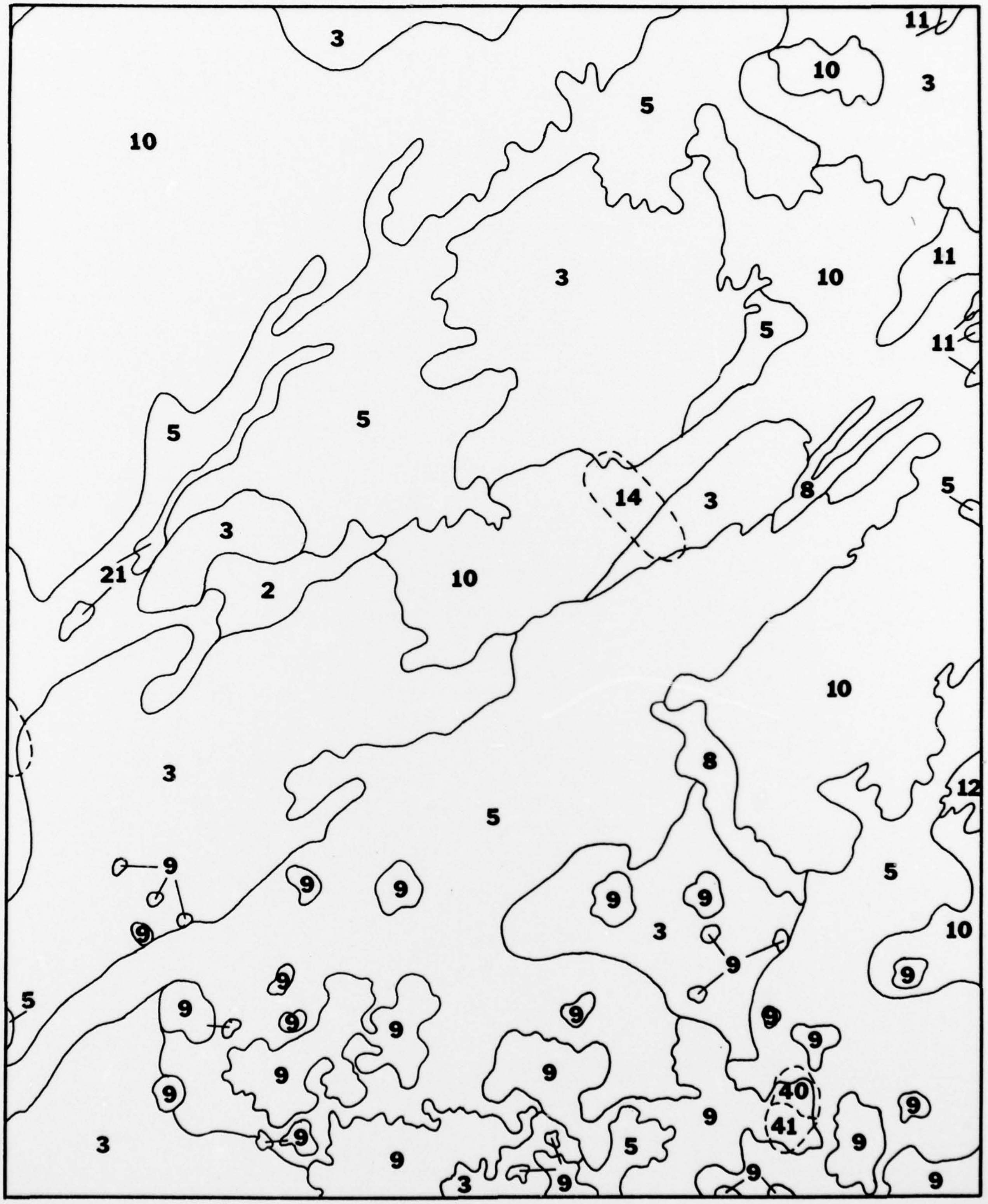
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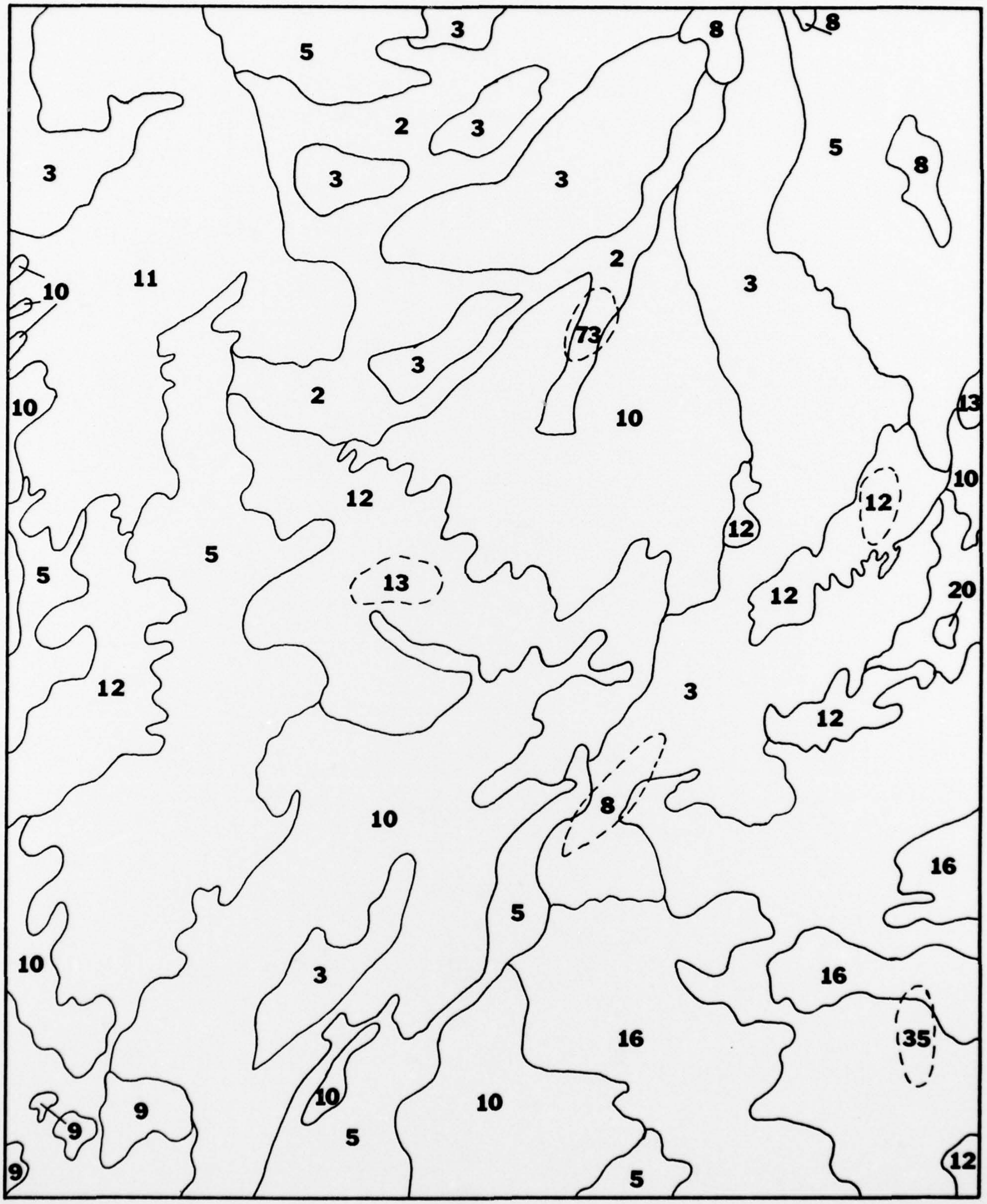
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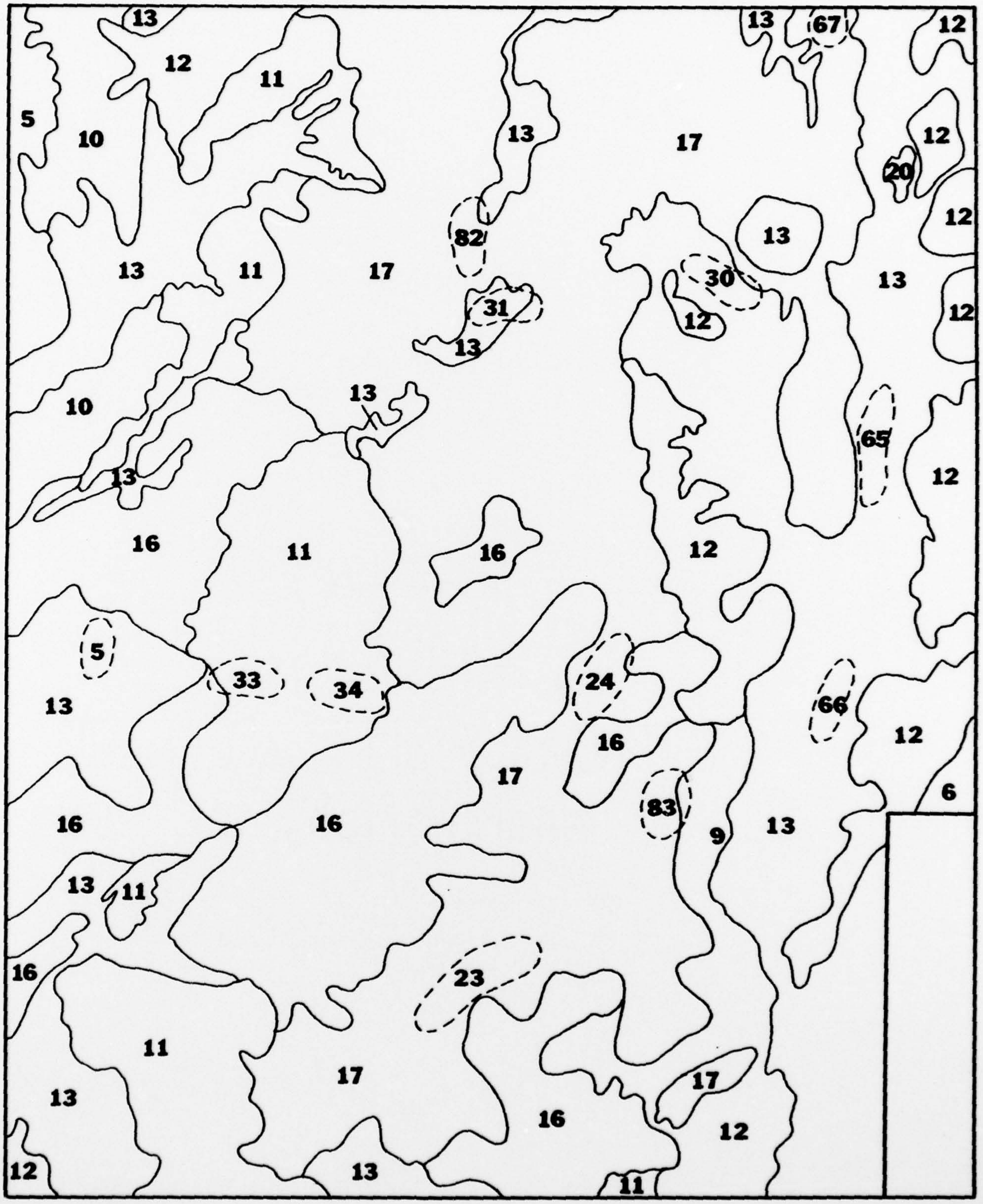
Sheet 26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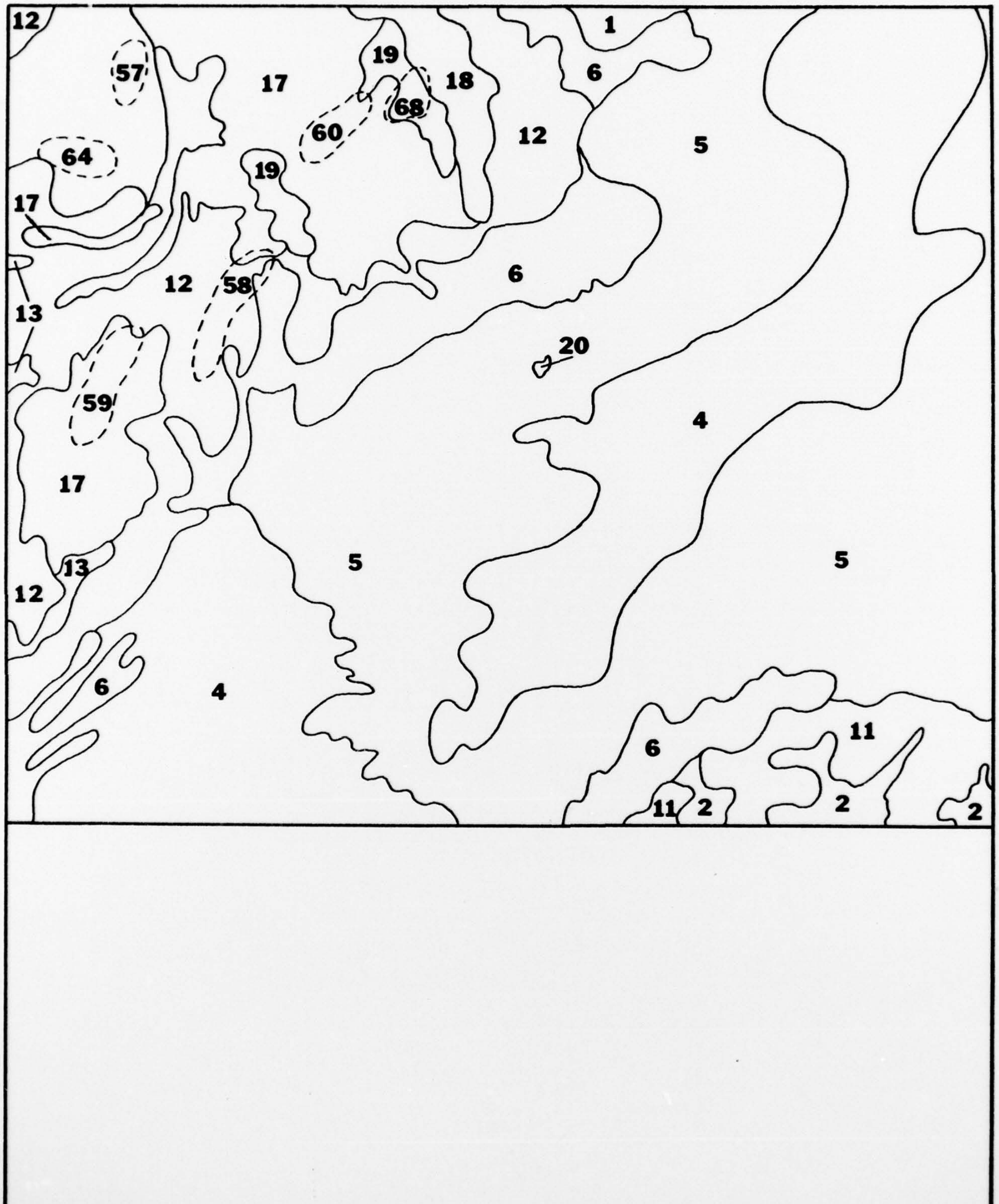
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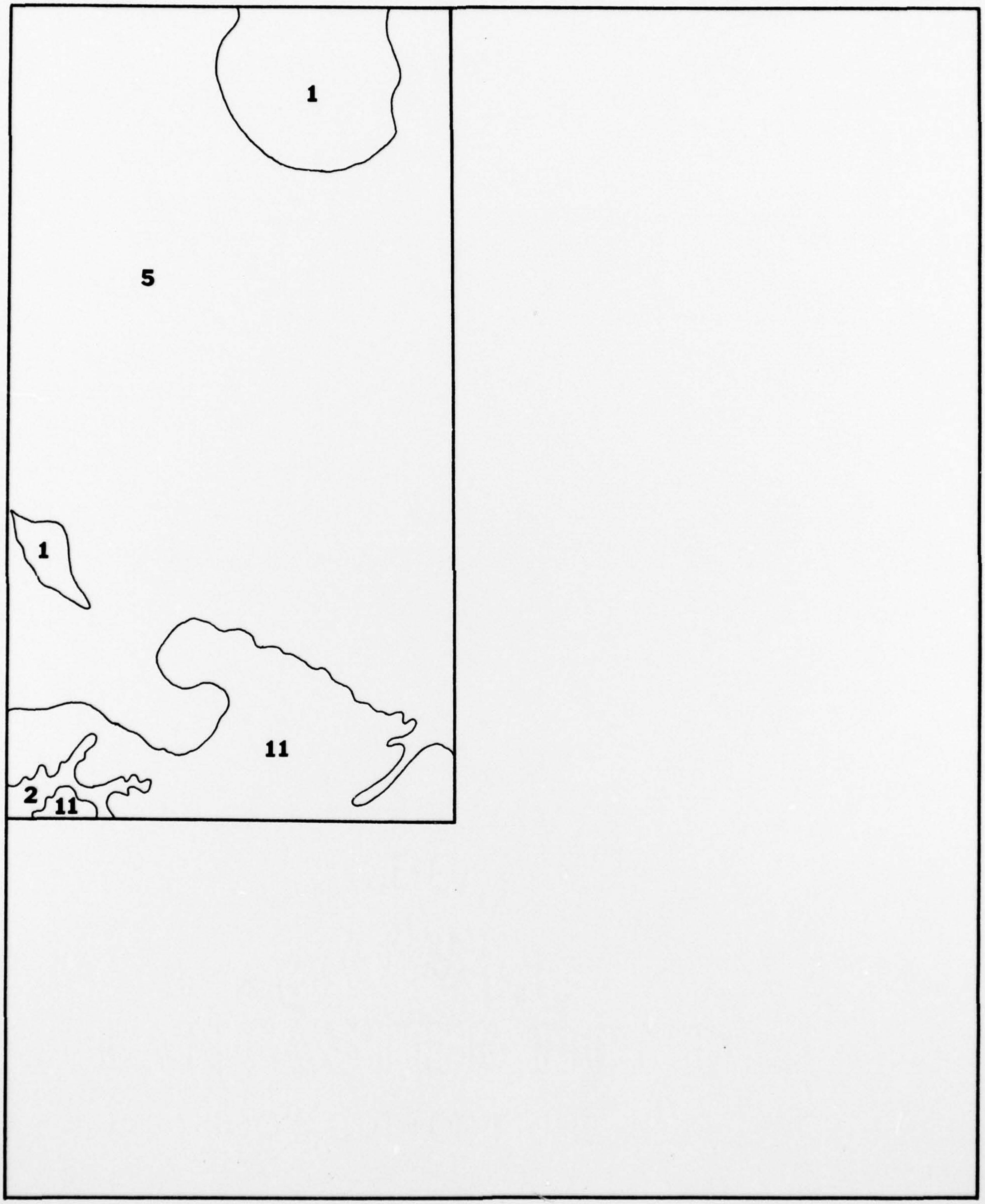
Sheet 28



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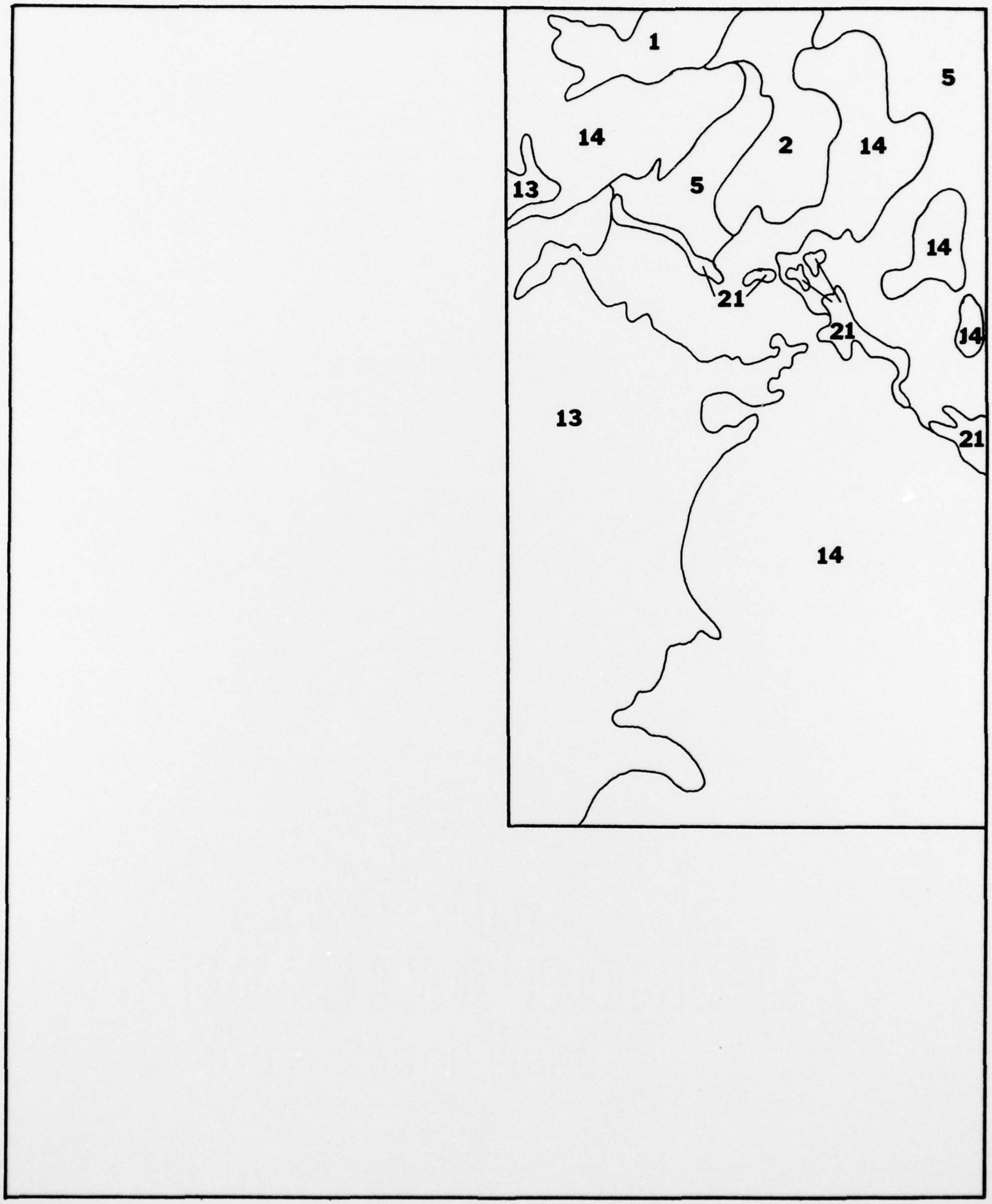

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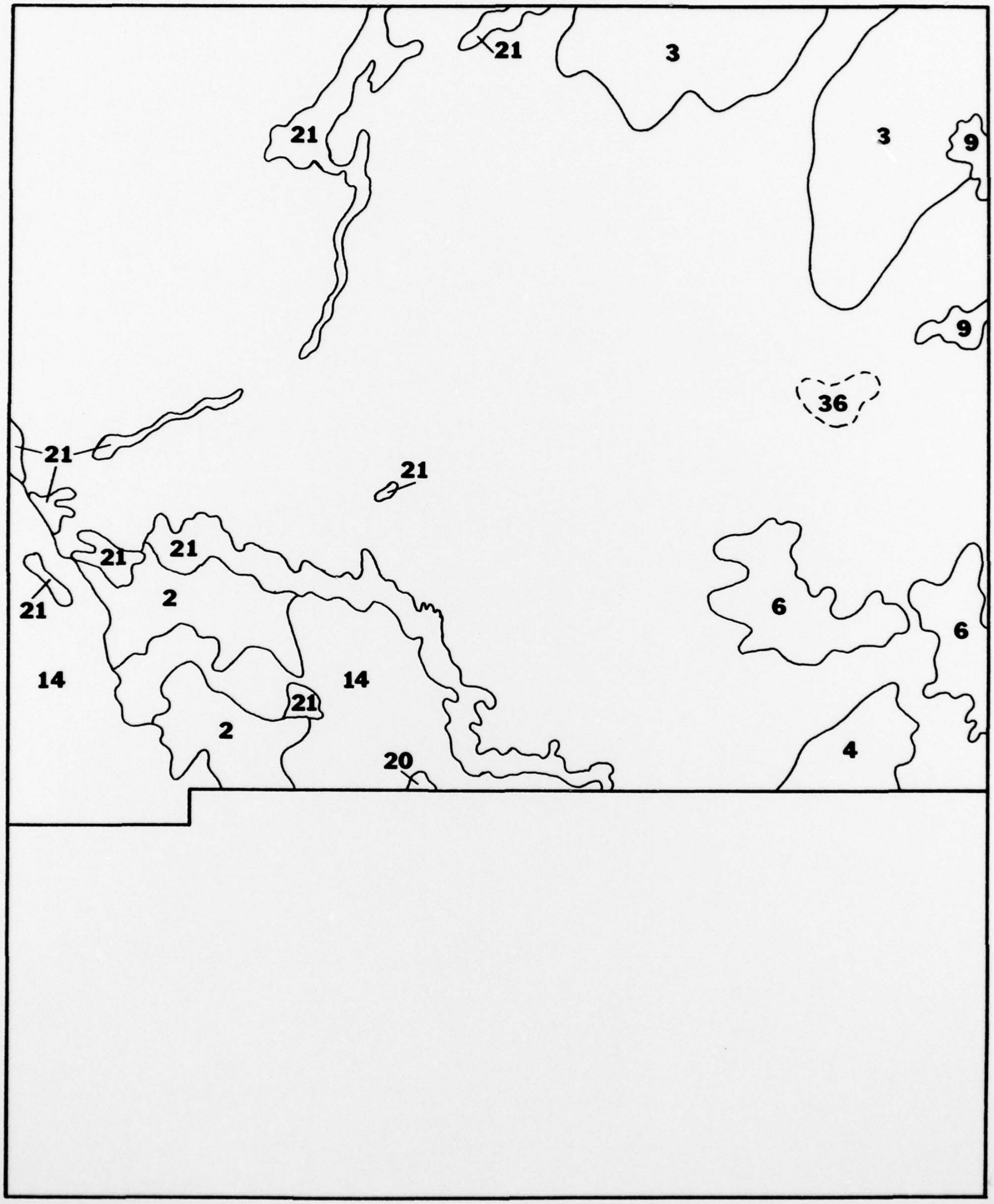

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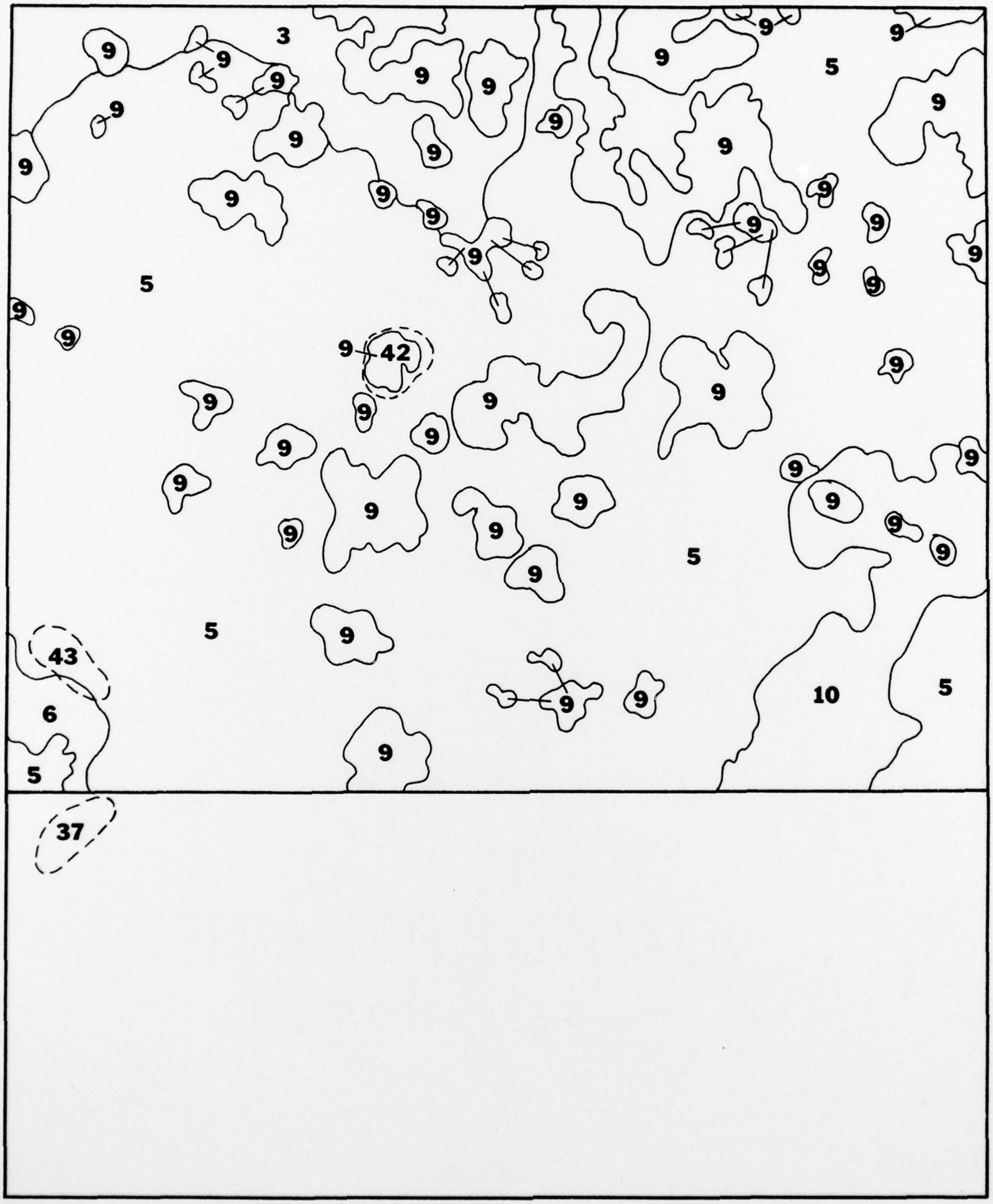

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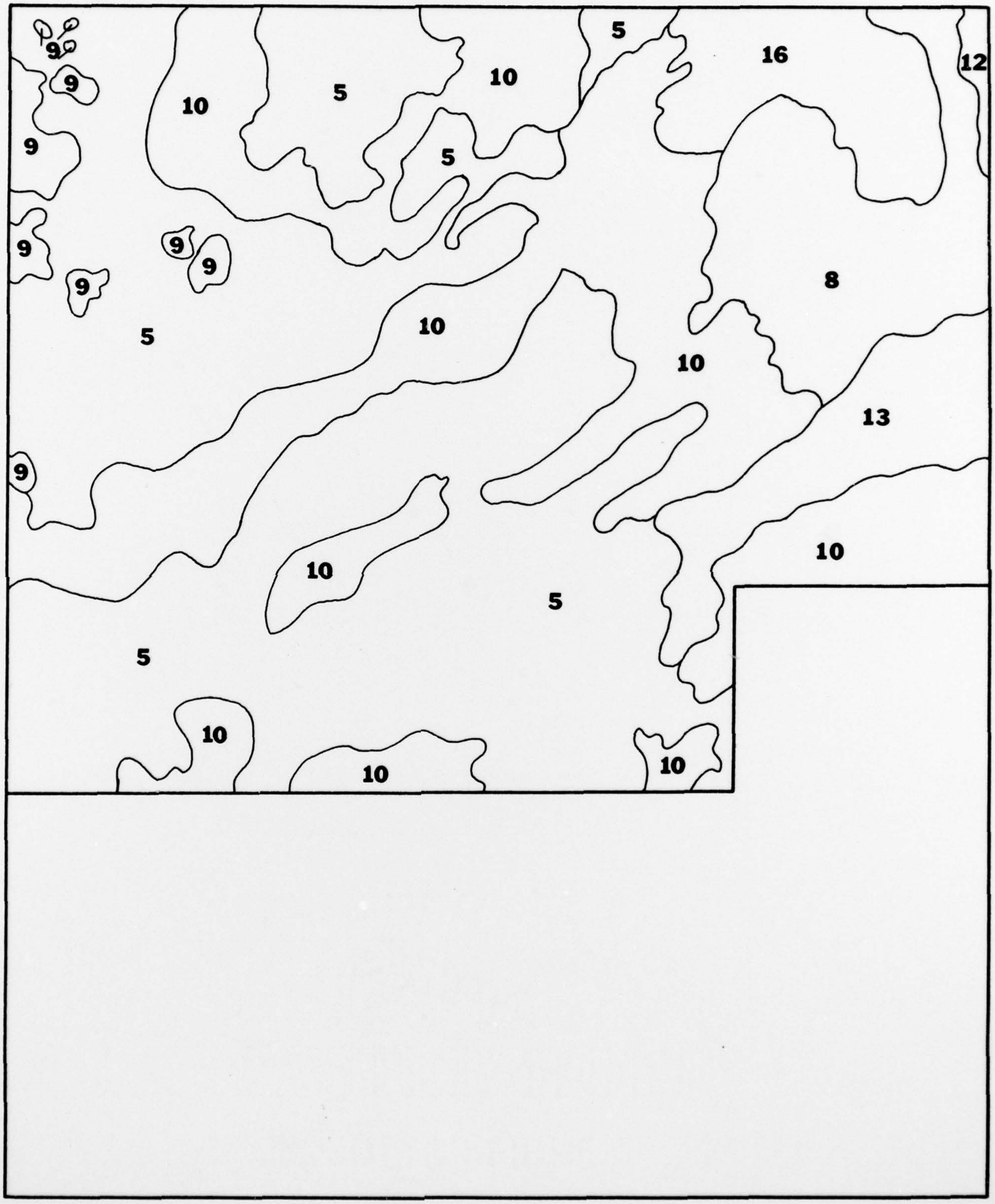

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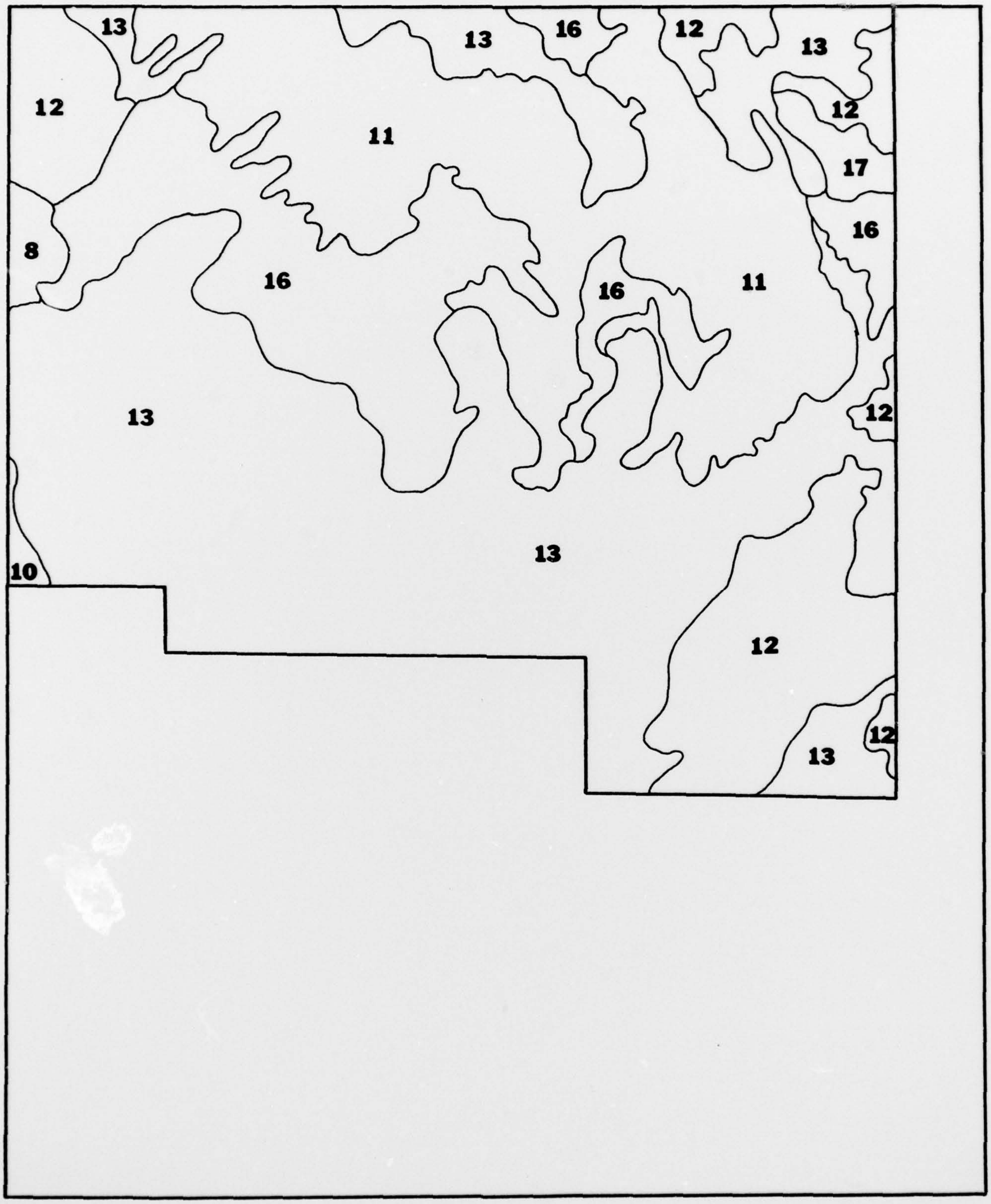

Sheet 34